The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

JERICO-S3 DELIVERABLE

Joint European Research Infrastructure for Coastal Observatories

Science, Services, Sustainability

DELIVERABLE #, WP# and full title	DELIVERABLE 5.2, WP5 - Technical handbook published within the OBPS Repository of BP for implementing and operating coastal observatories [JERICO Deliverable 5.2. Electronic Handbook for Mature Platforms: Mooring - HF Radar - FerryBox – Glider, Version 1.0].
5 Key words	Best practices, ocean observation, harmonization, standards, mature platforms
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Final version date/ Submission date	31.01.2023

Nature: R=Report

(R = Report, P = Prototype, D = Demonstrator, O = Other)

Dissemination level : PU

PU = Public, PP = Restricted to other programme participants (including the Commission Services), RE = Restricted to a group specified by the consortium (including the Commission Services), CO = Confidential, only for members of the consortium (including the Commission Services)

GRANT N°: 871153
PROJECT ACRONYME : JERICO-S3
PROJECT NAME : Joint European Research Infrastructure for Coastal Observatories - Science, services, sustainability
COORDINATOR : Laurent DELAUNEY - Ifremer, France - JERICO@ifremer.fr

5

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

DOCUMENT TECHNICAL DESCRIPTION

Document ID	JERICO-S3-WP5-D5.2-31.01.2023-V1.1

REVISION HISTORY

Revision	Date	Modification	Author
V1.0	31/01/2023	Submitted to coordinator	All the authors
V1.1	13/04/2023	Page number added in the index	Carlo Mantovani

APPROVALS

	Name	Organisation	Date	Visa
Coordinator	Laurent Delauney	Ifremer	13/04/2023	
WP Leaders	Julien Mader Carlo Mantovani	AZTI CNR	01/01/2023 01/01/2023	JM CM

Diffusion list

Consortium beneficiaries	Third parties	Associated Partners	other
X			

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

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GLOSSARY

Item	Definition

Best practice	A best practice is a methodology that has repeatedly produced superior results relative to other methodologies with the same objective
Convergence	Agreement on a recommendation for a common practice in the selected areas
GOOS	Global Ocean Observing System
Harmonization	Harmonisation refers to the practices which improve the comparability of variables from separate studies, permitting the pooling of data collected in different ways, and reducing study heterogeneity.
IAS-GOOS	Intra-Americas Sea Global Ocean Observing System
Interoperability	The ability of different systems, devices, applications or products to connect and communicate in a coordinated way, without effort from the end user. While the term was initially defined for information technology or systems engineering services to allow for information exchange, a broader definition takes into account social, political, and organizational factors that impact system-to-system performance
IOCARIBE	IOC of UNESCO Subcommission for the Caribbean and Adjacent Regions
IOOS	US Integrated Ocean Observing System
M&O	Maintenance and operation
Metadata	Data that describes other data. Meta is a prefix that in most information technology usages means "an underlying definition or description." Metadata summarizes basic information about data, which can make finding and working with particular instances of data easier; metadata may also be applied to descriptions of methodologies
OBPS	Ocean Best Practices System UNESCO/IOC
Ocean observing	Sustained observations of the ocean to understand climate change, predict weather and extreme events, to monitor ocean health, to support nations sustainable and blue economic growth, and adaptation to climate change. Data from ocean observing supports good policy and provides an evidence base for real-time decision-making, tracking the effectiveness of management actions, guiding adaptive responses to sustainable development, and supports businesses and jobs in the marine economy
Platform	Ocean observing platform, a fixed or mobile technological structure hosting sensors for acquisition of physical and biogeochemical variables for ocean and atmospheric and

	biological variables for the ocean
QA/QC	A combination of quality assurance, the process or set of processes used to measure and assure the quality of a product, and quality control, the process of ensuring products and services meet consumer expectations.
Standards	Documents of requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose. Standards are created by recognized standards organizations.
Standard Operating Procedures	A set of step-by-step instructions compiled by an organization to help workers carry out complex routine operations
Sustainability	Availability of resources and funding for keeping a system running in the long-term
Value chain	The set of value-adding activities that one or more organizations perform in creating and distributing goods and services. In terms of ocean observing, the value chain approach can be applied to consider societal benefits of observations, data, analyses and assess the value of data and information features

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The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

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ACKNOWLEDGEMENTS

This report is funded under the JERICO-S3 project, which is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

The report includes contributions of many experts. Authors for the four major platform sections and their contributions are:

MOORING [Platform 1]: Manolis Ntoumas (HCMR): coordination and review of the work in the mooring platform; Klas Möller (Hereon): main author of cabled underwater systems; Paris Pagonis (HCMR); Lauri Laakso (FMI), Martti Honkanen (FMI), Laurent Delauney (Ifremer), Inês Martins (IH), Mauro Bastianini (CNR), Carolina Cantoni (CNR), Fabio Brunetti (OGS), Brix Holger (Hereon), Philipp Fischer (AWI), Julien Mader (AZTI): substantial contribution to the mooring chapter.

HIGH FREQUENCY (HF) RADAR [Platform 2]: Carlo Mantovani (CNR): coordination and review of the work, substantial contribution to the HF Radar Chapter; Lorenzo Corgnati (CNR): main author of the HF Radar data management section, substantial contribution to the HF Radar Chapter; Julien Mader (AZTI), Anna Rubio (AZTI), Emma Reyes (SOCIB), Jochen Horstmann (HEREON, formerly HZG): substantial contribution to the HF Radar Chapter.

FERRYBOX [Platform 3]: Yoana G.Voynova (Hereon, formerly HZG): coordination and review of the work, substantial contribution to the FerryBox chapter; Andrew King (NIVA), Jukka Seppälä (SYKE), Manolis Ntoumas (HCMR): edits and substantial contribution to the FerryBox chapter; Gisbert Breitbach (HEREON, formerly HZG): substantial contribution to FerryBox data-related sections.

GLIDER [Platform 4]: Nikolaos D. Zarokanellos: coordination and review of the work, main author of the Glider Chapter, co-author of the Glider data management section; Miguel Charcos Llorens (SOCIB) co-author of the Glider data management section; François Bourrin (CNRS): edits and substantial contribution to the Glider Chapter

Sections on data management for Ferrybox, HF Radar and Glider platforms have been developed in JERICO-S3 D6.3 (to be published) and copied here with minor adaptations.

2. EXECUTIVE SUMMARY

Harmonization across monitoring of coastal Europe has been an emphasis of the JERICO projects. The monitoring resources span geography, diversity of sensors and platforms, and the availability of local resources. With the growing importance of sustainability and understanding of the impacts of human activity on the sea, having a comprehensive and holistic perspective on the coastal seas is essential. This has been expressed through the *Marine Strategy Framework Directive*[1] (MSFD) , https://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm and other European documents as well as national imperatives.

Coastal monitoring has been supported by national and project resources. Creating a harmonized European-wide Research infrastructure for coastal observing and information is a primary goal of JERICO [Farcy, et al, 2019]. Harmonization encompasses many actions. An important one is that data are collected according to commonly-accepted procedures and are interoperable. For this, a series of best practices is evolving for methods used in data collection and, more broadly, in the creation of decisionable information.

JERICO has been motivating the creation of best practices for over a decade and has documented procedures in all aspects of coastal observations. These procedures come in many forms (e.g., standard operating procedures or manuals) with varying levels of acceptance and maturity. In some cases, there may be multiple procedures to achieve the same objective, with the result that the selection of the best procedure is unclear.
This report addresses some of these challenges by introducing a refined scale of best practice maturity levels. These levels cover two key objectives: the status of the methods documentation and the degree to which the methods have been widely and effectively implemented. This is done through "A Best Practices Maturity Model for Methods and their Applications", which is introduced for the first time (see the Introduction for more information). The report then collects the best practice documents of JERICO and looks at their levels of maturity.
This report addresses best practices in the context of four mature JERICO observation networks: moorings, high frequency radar coastal monitoring, ferry boxes and underwater gliders. These systems are described in detail, covering the platform, the sensors and, with the exception of the moorings, the data management. With this background, the best practices related to each of the systems are given. The practices that exist are important for interoperability and trust in the data, but there are gaps in practices and these will need to be identified and addressed.

The three contributions of this report are: 1. an expanded maturity model for best practices; 2. recommendations for further implementation and maturing of best practices for coastal observations; 3. a master table of JERICO and other BPs as a reference for mature systems.

[1] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance) (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0056&from=EN)

3. INTRODUCTION

This handbook is intended to provide platform operators and scientists with a guide for the creation and operation of four types of mature observation platforms. This is done in the context of the JERICO Research Infrastructure (RI). The JERICO RI has long recognized that common methods or best practices used across similar platforms will improve data transparency and interoperability. For mature coastal observing platforms that are operational, the use of best practices is particularly important. Thus, we start this handbook with a discussion of such practices and define the levels of practice maturity and how they relate to the mature systems that are the focus here.

3.1. Processes documentation and their evolution toward best practices

The foundation for a "best practices culture" is the existence of widely used practices that are formally defined, documented and support evolution. The documentation must be sufficient so that people knowledgeable in the field can successfully execute the process and have the same outcomes that the process creators achieved. The process is replicable, but may not be optimized or adapted to efficient use in diverse local environments. As the practices mature further, broader adoption will test the practices in many environments to ascertain the applicability to diverse regional missions. For best practices, there needs to be a means of monitoring this evolution, through metrics, controls and analyses. As best practices reach maturity, more formalized metrics and key performance indicators should be defined and documented as part of best practices evolution.

Before moving to the details of an approach for best practices, the definition of a best practice is needed. A best practice has been defined as a "*methodology that has repeatedly produced superior results relative to other methodologies with the same objective; to be fully elevated to a best practice, a promising method will have been adopted and employed by multiple organizations"* [Pearlman, et al, 2019]. The creation of a best practice starts with the recognition and confirmation of a need. A team develops the content of the practice and invites community review. With the community feedback incorporated into the practice process, the practice may be published in a best practices repository. A publication in a peer reviewed journal may also be done. (Figure 3-1)

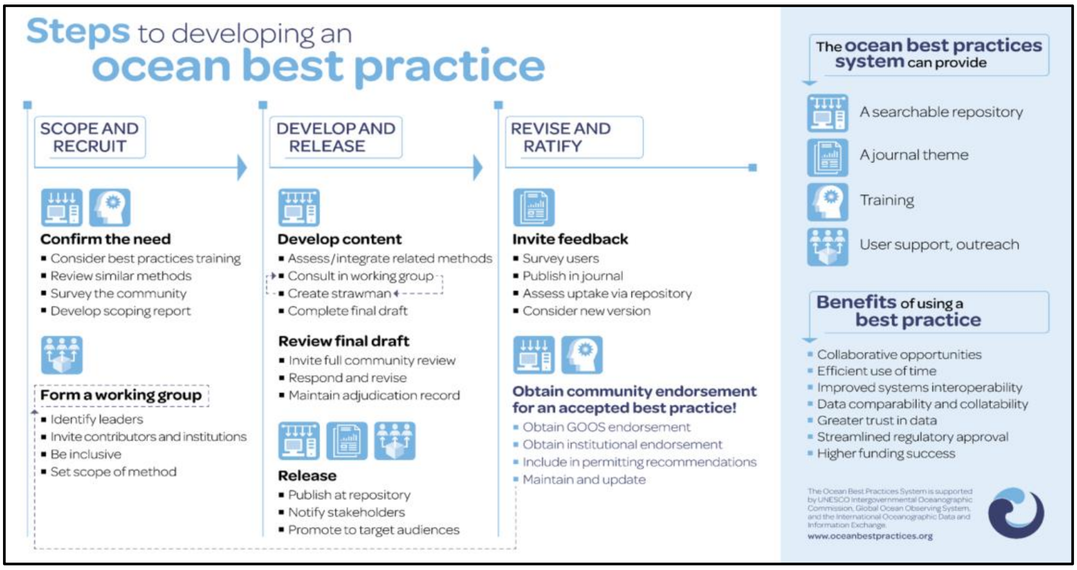

Figure 3-1. The creation and evolution of a best practice in the field of ocean observing [Przeslawski, 2021]

3.2. The Value of Best Practices in JERICO-RI and previous work

JERICO-S3 Project brings together a large number of multiplatform marine observatories from most European countries. An inventory of those platforms, including other platform candidates to enter the future JERICO Research Infrastructure (RI), is available through an interactive map in the JERICO-RI website (https://www.JERICO-ri.eu/JERICO-ri-catalogue/#/search?from=1&to=30). [link to JERICO-S3 D6.2]

Each observatory is managed independently and in principle has a different identity in terms of historical development, available resources, and management rules. Becoming part of a pan European Research Infrastructure however requires a certain level of harmonization across technologies, methodologies and procedures.

Harmonization through definition and use of best practices has been a foundation for the JERICO RI since the FP7 JERICO Project (2007-2013) https://www.jerico-ri.eu/jerico-fp7/,

and the related concept of a JERICO Label was developed subsequently. The **JERICO Label** has been defined as "… *a set of criteria defined to ensure standardisation and interoperability, and the quality of data for coastal observatories"* [Nair, et al, 2019], with three targeted qualities chosen as yardsticks for facilities and capabilities:

Sustainability: availability of funding for keeping a system running in the long-term (>5 years);

Operationality: the level of efficiency of the process of taking acquired data from raw to quality-assured and available for use in real-time and/or delayed mode;

Observing/research purpose ("fitness for purpose"): the completeness of the list of parameters handled by a system in relation to its scientific and/or other operational goals.

Ultimately, each component of the JERICO RI should aim to satisfy all these criteria. Quality assessment and monitoring of performances of the RI, for instance, highly benefits from common procedures within the network.

JERICO RI should necessarily demonstrate an added value that is greater than the mere sum of the single observatories. One of the strengths will be the capacity to bring all the observatories to a state of art by following harmonized practices in terms of platforms, sensors and data management. This condition is a prerequisite for the RI to provide services that single observatories will not be able to provide alone.

The employment of best practices in routine operations is also a component of the foreseen Strategic Operational Plan, which in turn is another required element of the JERICO Label.

The JERICO-FP7 consortium (Infra-IA, 2011-2014) was formed from the existing and unconnected communities that were mainly relying on autonomous observation systems with capability for continuous operations: ferryboxes, gliders and moorings (also called fixed platforms). Harmonization actions were initiated first [Ntoumas, et al, 2019] for moorings, ferryboxes and gliders. In the following step, JERICO-NEXT (Infra-IA, 2015-2019), HF Radars were added and some significant progress on achieving common best practices and standards in the European network were achieved [Corgnati, et al, 2018].

An evaluation of the harmonization process, intended as the adoption of best practices developed within JERICO network, was documented in JERICO-Next deliverable D2.3: "Report on ongoing harmonization initiatives within the JERICO network for the following three key technology areas: Moorings, Ferryboxes and Gliders" (https://www.JERICO-ri.eu/download/JERICO-next-deliverables/JERICO-NEXT_D2.3-Ver2_Final.pdf) [Ntoumas, et al, 2019]. The report indicated a moderate level of harmonization for the three technology areas based, however, on a few general recommendations rather than on the integral adoption of a set of well-documented best practices.

For coastal ocean observation, a number of recommendations for best practices relating to platforms, sensors, and data management have been released also in the framework of other international projects, programmes, and collaborations.

There are challenges in adopting a homogeneous set of best practices. In many cases, best practices reflect the infrastructure and cultural environment of observing systems. There may be many practices for achieving a particular objective and it can be unclear which is best. A consistent approach is needed to identify and select practices which should be part of the foundation for coastal ocean observing.

3.3. JERICO-S3: a new step toward best practices identification and harmonization

This Handbook is to consolidate the previous work and provide a single resource for JERICO RI mature platforms. In doing this for best practices, common questions are: which method can be considered a best practice and is there a measure of maturity for best practices that we can identify? Does the process described in the best practice follow guidelines produced by experts? Is the documentation easily findable; does the documentation allow easy readability; machine to machine discoverability and indexing; proper recognition of sources; and completeness with respect to all aspects of user interest? Have they been reviewed by independent experts? [Horstmann, et al, 2020]

There are challenges facing a new user. For example, as mentioned above, there can be multiple practices that have the same objective. “Which one should I use?” New users may have a hard time selecting one practice over another. What are the options to support users in the adoption of effective and efficient best practices?. A method of endorsement was developed and tested by GOOS and OBPS to identify preferred practices [Hermes (ed.), 2020]. Another option is a user rating system which can identify effective practices for a given application. This could be supported through a feedback loop which is envisioned for best practices.

This document addresses some of the recommendations developed within and outside the JERICO community to answer the questions above, initially from the perspective of the JERICO evolution to a Research Infrastructure. It is specifically addressed for four categories of marine observing platforms, namely **Moorings, High Frequency Radar, Ferrybox and Underwater Gliders**[2], which are considered **mature platforms**[3] in the JERICO infrastructure.

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[2] Mooring: a tethered collection of oceanographic instruments at a fixed location that may include seafloor, mid-water and surface components. The above definition is taken from the L06 SeaDataNet Vocabulary (SEAVOX PLATFORM CATEGORIES https://vocab.seadatanet.org/v_bodc_vocab_v2/search.asp?lib=L06).

[3] Mature platforms are those that comply with specific criteria from the readiness of requirements, observation elements and data and information products (FOO, 2012).

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4. A BEST PRACTICES MATURITY MODEL FOR METHODS AND THEIR APPLICATIONS

4.1. Introduction

Interoperability across the JERICO Research Infrastructure must be supported by using consistent, tested and mature methods for each step of the ocean value chain from observations to data management and ultimately to the end user applications and societal impacts (Figure 4-1)

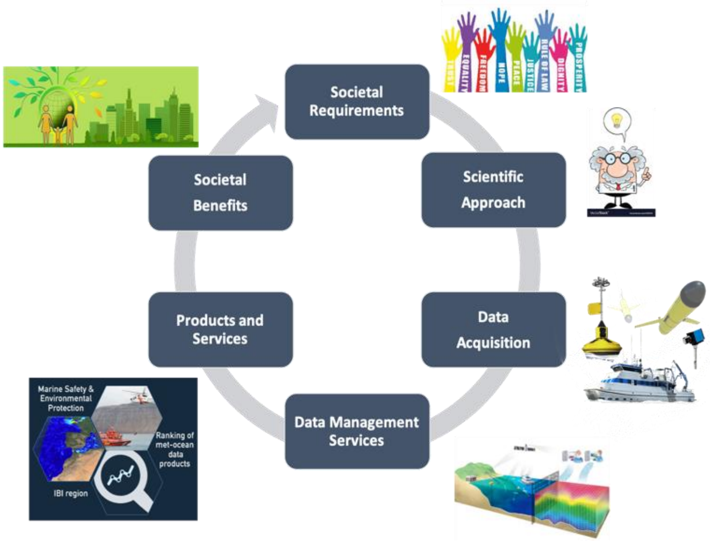

Figure 4-1: Ocean observing value chain

Descriptions of the maturity of best practices have been available in industry, where they are used to monitor the efficiency of business processes [Tarhan, et al, 2016; Lutkevich, 2022] Generally, these are described in terms of business-process maturity models. The models have several objectives: benchmark internal performance; catalyze performance improvement; and create and evolve a common language to understand performance. The last supports a commitment to foster the engagement of all stakeholders. The degree of maturity described in these business models is done through assigning levels related to the degree to which processes are documented and adhered to. An example of these levels was given in https://www.stratechi.com/process-maturity-levels/. Another example is the Software Capability Maturity Model (CMM). The CMM model is interesting in that there are decades of experience with the processes and it has parallels to the best practices maturity model that will be addressed below.

The Capability Maturity Model (CMM) is a methodology used to develop and refine an organization's software development process. The model describes a five-level evolutionary path of increasingly organized and systematically more mature processes. The levels are shown in Figure 4-2. [Lutkevich, 2022]

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

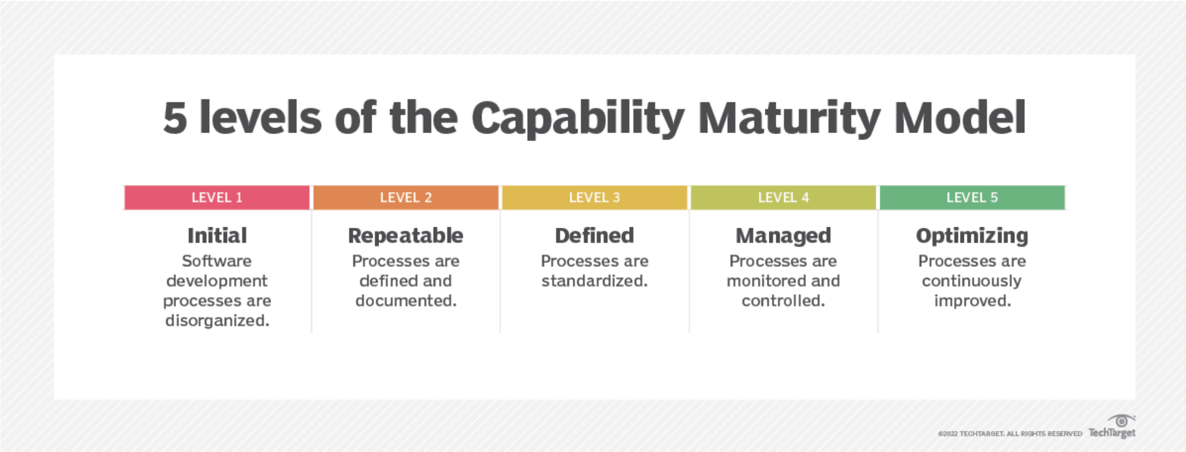

Figure 4-2. Five levels of the Capability Maturity Model

In the case of software, there are parallel paths in moving toward mature methods, one through ISO 9001 standards [https://www.iso.org/news/ref2685.html], and the other through processes for best practice evolution such as CMM. CMM is similar to ISO 9001. The main difference between CMM and ISO 9001 lies in their respective purposes: ISO 9001 specifies a minimal acceptable quality level for software processes, while CMM establishes a framework for continuous process improvement. It is more explicit than the ISO standard in defining the means to be employed to that end [Lutkevich, (2022]. For the discussions in this report, we include, wherever possible, both best practices and standards. The point here is that they can have different objectives on the same topic and they are formed through different processes [Pearlman, et al, 2019].

Another facet of the CMM approach is the way it has evolved. Two decades ago, CMM Integration (CMMI) was created as a newer, updated model of CMM. CMMI's objective is to integrate and standardize CMM, which has different models for each function it covers. These models were not always in sync; integrating them through CMMI made the process more efficient and flexible. CMMI, thus, addresses not only the creation of processes, but their integration to support practical implementation. For example, CMMI includes additional guidance on how to improve key processes. It also incorporates ideas from Agile development and continuous improvement [Goldenson and Gibson, 2003].

4.2. Ocean Observing Maturity Model

Maturity models for observations have evolved over time. Technology Readiness Levels (TRL) (see Table 4.1), were created for space hardware systems by NASA and other agencies during the 1970s [Hirshorn and Jefferies, 2016]. The Framework for Ocean Observing (FOO) adopted and modified the space hardware TRL to use for ocean observing systems [FOO, 2012]. See Figure 4-3.

For best practices, the Ocean Best Practices System, building upon the FOO, defined a three-level maturity schema following the practices of the FOO [Ocean Best Practices System 2021]. Those three levels are described in Annex III - OBPS Document Data Sheet, Metadata field: Maturity Level - and users are requested to specify which level applies to the practice being submitted to the OBPS system. However, this evaluation scheme seems more related to the maturity of the process/methodology itself, and it does not fulfil the need of a comprehensive maturity assessment of the process description and adoption. This JERICO-S3 D5.2 report extends the three level FOO description into five maturity levels. In this expansion of the FOO description, criteria for best practices maturity are identified relating to maturity of the process description and maturity of the process adoption**.** To effectively address all of these, a five-level model provides more granularity at the higher levels of maturity, particularly for operational systems

Table 4-1. Technology Readiness Levels (TRL) were created for space hardware systems by NASA and other agencies during the 1970s. Only the four highest levels are shown here because the focus of this paper is on mature observing systems. The full NASA table is available at https://ntrs.nasa.gov/api/citations/20170005794/downloads/20170005794.pdf

TRL	Definition	Hardware Description	Software Description	Exit Criteria
6	System/ sub-system model or prototype demonstration in an operational environment.	A high- fidelity system/component prototype that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate operations under critical environmental conditions.	Prototype implementations of the software demonstrated on full-scale realistic problems. Partially integrate with existing hardware/software systems. Limited documentation available. Engineering feasibility fully demonstrated.	Documented test performance demonstrating agreement with analytical predictions.
7	System prototype demonstration in an operational environment.	A high- fidelity engineering unit that adequately addresses all critical scaling issues is built and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne, or space).	Prototype software exists having all key functionality available for demonstration and test. Well integrated with operational hardware/software systems demonstrating operational feasibility. Most software bugs removed. Limited documentation available.	Documented test performance demonstrating agreement with analytical predictions.

8	Actual system completed and "flight qualified" through test and demonstration.	The final product in its final configuration is successfully demonstrated through test and analysis for its intended operational environment and platform (ground, airborne, or space).	All software has been thoroughly debugged and fully integrated with all operational hardware and software systems. All user documentation, training documentation, and maintenance documentation completed. All functionality successfully demonstrated in simulated operational scenarios. Verification and Validation (V&V) completed.	Documented test performance verifying analytical predictions.
9	Actual system flight proven through successful mission operations.	The final product is successfully operated in an actual mission.	All software has been thoroughly debugged and fully integrated with all operational hardware/software systems. All documentation has been completed. Sustaining software engineering support is in place. System has been successfully operated in the operational environment.	Documented mission operational results.

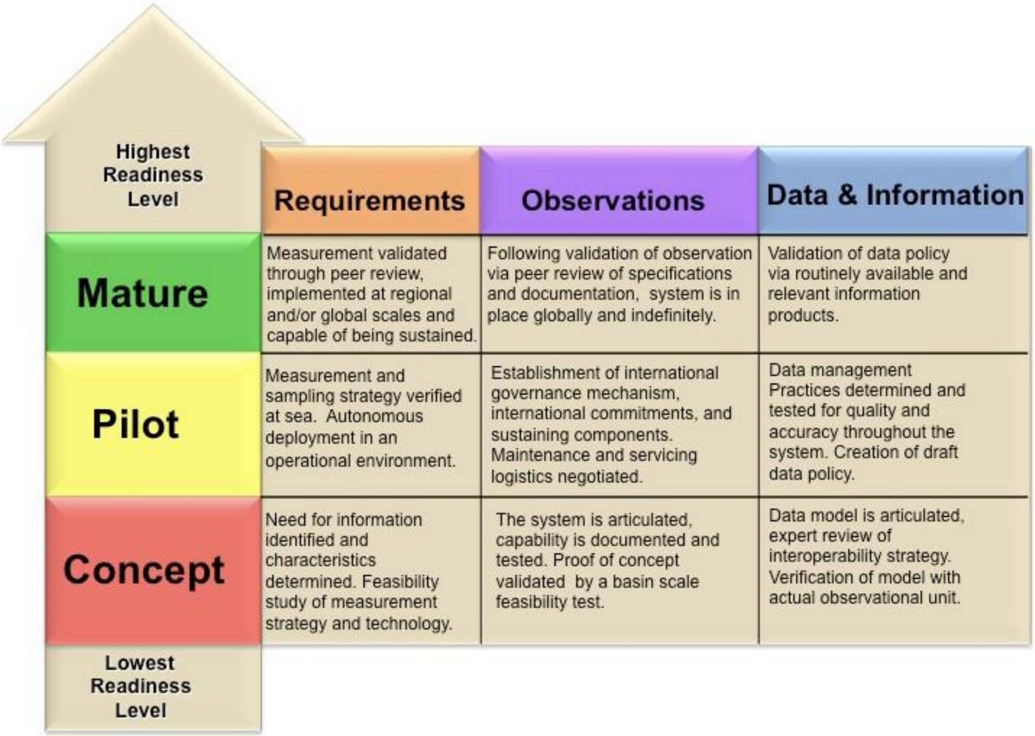

Figure 4-3 Framework Processes and Readiness Levels. Requirements, Observations, and Data and Information products move through readiness levels within the FOO Framework.

Focusing on the five-level model (Table 4.2 below), its two lowest levels include processes that are ad hoc and lack systematic discipline. In ocean observing, these conditions occur

when organizations create local practices for their working environment and project objectives, many of which are not well documented or retained for long-term reuse. Only the three highest levels, where processes are formally defined and implemented, can successful replication of practices be assumed. It is these levels that are the focus of this document.

Table 4-2 The five levels of maturity for ocean best practices

Level			Description
5		**Mature**	**Practices are endorsed by multi-institutional expert panels. Practices have formal diagnostic tools and user feedback loops supporting continuous improvement and optimization over the practice lifecycle. Practices have associated methods for training and sustainability. Practices are embedded into advanced information infrastructures.**
4		**Broadly adopted**	**Practices are widely adopted by multiple institutions. Practices with standardized formats and comprehensive metadata are in a sustained repository with DOIs assigned. Documents and metadata are machine-actionable. Practices have associated guidelines and metrics for their implementation, monitoring and evolution. Practices can be replicated with no prior experience in the process.**
3		**Defined and documented**	**Practices are formally defined and documented with metadata, are openly available, and can be replicated by independent practitioners with prior knowledge in similar processes.**
2		**Repeatable**	**Practices are defined and may be documented. It is repeatable by the process creator.**
1		**Formation**	**Practices are ad hoc with little documentation.**

The key to implementing a maturity model is a detailed description of the attributes in each of the levels. As the focus of this document is on practices related to mature observing systems, the levels where the practices are well documented is the focus, which are levels 3 to 5 in Table 4-2 above. To assign a maturity level to a particular practice, the characteristics of each level (levels 3-5 for this document), must be defined in detail.

For level 3, practices have four key characteristics: (1) they have sufficient detail to be implemented by others who will get the same outcome as the originator, however the practitioners must have relevant prior skill in similar processes; (2) the practices are openly available in a digital repository; ; (3) they have metadata sufficient to efficiently discover them including information on authors, etc.; (4) they follow a local template (e.g. a project deliverable template). It is however not a "best" practice as it is not used by multiple institutions.

Those practices which are used by multiple institutions and conform to the definition of best practice are at level 4 and level 5. The key attributes for level 4 are: (1) best practice is recommended/adopted by multiple institutions; (2) best practice document is available in OBPS or similar repository and has a DOI; (3) best practice document structure (e.g. index of contents) follows recommended templates from OBPS or similar Methodology Management Systems (MMS); (4) best practice document is described with metadata following recommendations from OBPS or from other similar MMS; and (5) the best practices document complies with formal requirements for machine-actionability. In addition, practices have associated guidelines and metrics for their implementation, monitoring and evolution. Practices can be replicated with no prior experience in the process.

The OBPS is a UNESCO Intergovernmental Oceanographic Commission sustained repository of more than 1770 practices. The repository offers natural language discovery (www.oceanbestpractices.org). OBPS offers metadata templates (as well as document templates) which are available for different elements of the ocean value chain. With the OBPS, each document is given a Digital Object Identifier (DOI) if one has not already been assigned. OBPS also manages version control linking updates to maintain the practice history.

For Level 5, best practices have the following attributes: (1) they are widely adopted globally; (2) formal tools are used for assessing the compliance of a given process/method to them; (3) there is a plan for their review and upgrade over intended lifecycle of the method and its documentation; (4) they are endorsed by expert panels from multiple institutions; (5) there is a mechanism for user feedback on the best practice; (6) practices are embedded into advanced information infrastructures; (7) knowledge of the best practices is sustained through user training. There will be variations in the implementation of practices for a given platform and key performance indicators should be identified both for the platform implementation and the integration at the network level.

A challenge with understanding the value and impact of a best practice is that feedback on its use (both implementation and outcomes) is limited. For best practices, at all maturity levels, to evolve, tools to monitor implementation are needed as well as feedback loops with

users. Ideally, there is a central repository supporting levels 3-5 practices which collects feedback information and supports optimization.

4.3. Maturity Model Criteria and their Capabilities

In order to allocate a best practice to a maturity level, another level of detail is needed. This can be done by reviewing the practice against a series of capability attributes that address the document maturity and/or the process and implementation maturity. In the attributes below, three levels of capability are identified: the capability does not exist, the capability exists on a limited scale, the capability is implemented across most or all stakeholders. It is anticipated that the maturity level of a practice may change depending on which of the three capability levels is appropriate for the practice. This can be a complex matrix if all best practices are considered as a group. To simplify the assignment of maturity levels, a minimum level of capability for a maturity level should be identified. Typically, though not always, capability 2 for a given criterion should be considered as the minimum level. Ultimately, all criteria should reach capability 3.

1) Document is openly available in a sustained digital repository
Capability 1 - no
Capability 2 - yes, in a generic repository
Capability 3 - yes, in the sustained OBPS or similar repository with a DOI

2) Best practice document has sufficient detail to be implemented by other practitioners
Capability 1: no
Capability 2: Yes, user needs extensive and relevant prior skill
Capability 3: Yes, non-expert users with limited prior knowledge can implement it

3) Best practice document is described with metadata
Capability 1: no
Capability 2: comprehensive metadata
Capability 3: metadata conforms to OBPS or other global standards

4) Degree of adoption of a documented practice
Capability 1: only one organization uses this documented practice.
Capability 2: multiple organizations (e.g. in a network) use this documented practice
Capability 3: this documented best practice is widely adopted globally

5) Best Practices document format conforms to existing recommendations
Capability 1: no
Capability 2: conforms to local recommendations
Capability 3: conforms to OBPS templates or other global standards

6) Best Practices Document compliance with formal requirements for machine-actionability
Capability 1: no
Capability 2: compliance with OBPS or similar recommendations for full machine-actionability
Capability 3: practices are embedded in advanced information infrastructures

7) Monitoring protocols are applied for assessing the compliance of a given process/method to the best practices document
Capability 1: no
Capability 2: informal recommendations and procedures are used
Capability 3: formal monitoring tools and protocols are widely adopted

8) There is a commitment for review and upgrade over intended lifecycle of the process and documentation
Capability 1: no
Capability 2: yes through a series of guidelines and predefined review periods
Capability 3: yes through a specific protocol (e.g. all the steps, dates, contributors are defined)

9) Practices have formal diagnostic tools and user feedback loops supporting continuous improvement and optimization
Capability 1: no
Capability 2: practices have guidelines for their continuous improvement
Capability 3: diagnostic tools and user feedback loops implemented

10) Best Practice endorsement
Capability 1: no
Capability 2: best practice is recognized by multiple institutions
Capability 3: best practice is formally endorsed through recognized expert panels

11) Knowledge of the best practices is sustained through training or capacity development mechanisms
Capability 1: no
Capability 2: structured and documented training available

A summary of the above capabilities is given in Table 4-3. In all cases, a higher level includes all attributes of lower levels. Within each maturity level, capabilities are not necessarily sorted in terms of increasing maturity.

Table 4-3: Capabilities of best practice maturity for levels 3 to 5.

Capabilities	Level 3	Level 4	Level 5
3.1 Best practice document is openly available in a digital repository	✓	✓	✓
3.2 Best practice document has sufficient detail to be implemented by other practitioners with extensive and relevant prior skill in similar processes	✓	✓	✓
3.3 Best practice document is described with comprehensive but not standard metadata	✓	✓	✓
3.4 Best Practices document format conforms to local recommendations	✓	✓	✓

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4.1 Best practice document is openly available in the sustained OBPS repository with a DOI		✓	✓
4.2 Best practice document has sufficient detail to be implemented by other practitioners with no prior experience in the process		✓	✓
4.3 Best practice document is described with metadata that conforms to OBPS or other global standards		✓	✓
4.4 Multiple organizations (e.g. in a network) recognize and use this documented practice		✓	✓
4.5 Best practice document format (e.g. index of contents) conforms to OBPS templates or other global standards		✓	✓
4.6 Best practice document is compliant with OBPS or similar recommendations for full machine-actionability		✓	✓
4.7 informal recommendations and procedures are used for assessing the compliance of a given process/method to the best practices document		✓	✓
4.8 There is a commitment for review and upgrade over intended lifecycle of the process and documentation through a series of guidelines and predefined review periods		✓	✓
4.9 Practices have guidelines for their continuous improvement		✓	✓
5.1 Best practice is widely adopted globally			✓
5.2 Machine-actionability supports practices to be embedded in advanced information infrastructures			✓
5.3 Formal monitoring tools and protocols are widely adopted for assessing the compliance of a given process/method to the best practices document			✓
5.4 There is a commitment for review and upgrade over intended lifecycle of the process and documentation through a specific protocol (e.g. all the steps, dates, contributors are defined)			✓
5.5 Practices have formal diagnostic tools and user feedback loops supporting continuous improvement and optimization			✓
5.6 Best practice is formally endorsed through recognized expert panels			✓

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

5.7 Knowledge of the best practices is sustained through structured and documented training			✓

Applying these maturity assessment criteria to practices is a combination of fact and judgement, similar to ratings for hotels and restaurants. A listing of best practices developed under JERICO for the four major mature platforms included in this report is provided in Annex I. The list includes a few other best practices documents developed outside JERICO RI but still relevant for the purpose of the present deliverable.

In order to provide a quick visual reference for users, a practice can be assigned from one to five stars corresponding to its maturity level attributes. This is not meant to be a quantitative statement, but a guideline for users. Half stars are given when a practice has one or more of the maturity level attributes, but not all of them. As with all five-star rating levels, the number of stars may change as the practice matures or is updated by another version.

In the above discussion, the maturity level of best practices is defined and enumerated for JERICO-defined best practices. There are additional key concepts which must be considered at a system level. This includes maturity for integration into networks, the commonality of methods across the network and consistency in the level of reporting. In the following sections, information on four mature observing platforms is provided. These are Moorings, HF Radars, FerryBoxes and Underwater Gliders;

Each of the following sections of this document has three components: platform, sensors and data. The attributes of the system in each of these areas are described including a description of components, their operational characteristics and related best practices and standards. The tables of best practices are derived from the master table of practices in Annex I In addition, relations among the components are considered. For example, the sensors used in the platforms are given in Annex II, which describes the sensor attributes. The data management is related to both the platform type and the sensors used on the platform, and the related section for all the platforms, except Mooring, has been developed in JERICO-S3 D6.3 - "Data Management Best practices report for physical and BGC platforms" (to be published) and kindly made available for inclusion in each mature platform description of the present handbook.

As an exemplar for applying the maturity model, a best practice was selected from the JERICO inventory: Recommendation Report 2 on improved common procedures for HFR QC analysis, JERICO-NEXT Deliverable 5.14, Version 1.0. (Annex I ID = 20)

Table 4-4: Maturity assessment of a JERICO best practice.
(1 to 5 stars; full star = level completed, half star = partially compliant)
See Table 4-2 for The five levels of maturity for ocean best practices

Recommendation Report 2 on improved common procedures for HFR QC analysis, JERICO-NEXT Deliverable 5.14, Version 1.0. (Annex I ID = 20)	

Maturity Level 1 2 3 4 5	
✓	3.1 Best practice document is openly available in a digital repository
✓	3.2 Best practice document has sufficient detail to be implemented by other practiti and relevant prior skill in similar processes
✓	3.3 Best practice document is described with comprehensive but not standard meta
✓	3.4 Best Practices document format conforms to local recommendations
✓	4.1 Best practice document is openly available in the sustained OBPS repository wit
✓	4.2 Best practice document has sufficient detail to be implemented by other pract experience in the process
X	4.3 Best practice document is described with metadata that conforms to OBPS or ot
✓	4.4 Multiple organizations (e.g. in a network) recognize and use this documented pr
X	4.5 Best practice document format (e.g. index of contents) conforms to OBPS temp standards
X	4.6 Best practice document is compliant with OBPS or similar recommendations fo actionability
✓	4.7 Informal recommendations and procedures are used for assessing the complian process/method to the best practices document
✓	4.8 There is a commitment for review and upgrade of the process and documentatio lifecycle, through a series of guidelines and predefined review periods
X	4.9 Practices have guidelines for their continuous improvement
✓	5.1 Best practice is widely adopted globally
X	5.2 Machine-actionability supports practices to be embedded in advanced informatio

✓	5.3 Formal monitoring tools and protocols are widely adopted for assessing the com process/method to the best practices document
x	5.4 There is a commitment for review and upgrade over intended lifecycle of the pro documentation through a specific protocol (e.g. all the steps, dates, contributors are
x	5.5 Practices have formal diagnostic tools and user feedback loops supporting conti and optimization
x	5.6 Best practice is formally endorsed through recognized expert panels
x	5.7 Knowledge of the best practices is sustained through structured and documente

As mentioned earlier, best practices do not move consistently higher in maturity, completing one level before moving on to the next. Table 4-4 is a mapping of a relatively mature practice which has attributes in both level 4 and level 5, but having completed neither fully. Having a star rating allows a quick overview of the practice maturity. It is a subjective measure and in the practices in the table both level 4 and level 5 are partially complete. Thus a rating of would be a logical summary of maturity. However, two half stars are not a tradition in star ratings. Further discussion and more practices will provide exemplars that can develop a consistent level description.

As a final remark, as said at the beginning of this introduction, the JERICO Label requires that a series of criteria are satisfied by JERICO coastal observatories. Among them, best practices for operating observing platforms must be defined and adopted. A number of Key Platform Performance Indicators (KPPIs) are being defined in JERICO-S3 D5.3 (to be published) for monitoring the JERICO Label implementation. The present Handbook is therefore expected to help such a process, allowing the JERICO community to define specific KPPIs on the existence, maturity and application of best practices.

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5. PLATFORM 1: MOORING

How to use this Handbook

The Handbook is intended for a wide and diverse audience. It allows quick and easy access to the most appropriate sections. All readers are encouraged to read this introduction and the table below will help you decide which sections are likely to be most relevant to you.

Audience	*Recommended sections*
Moorings Operational managers, M&O staff, Moorings technicians, Coastal Ocean Observing System managers	5.2, 5.3 Platform Description
Moorings Operational managers, M&O staff, Moorings technicians, manufacturers	5.4 Sensor(s) and integration into the platform
Marine Data Managers, Moorings data users, trainers, students	5.5 Data and Data Management Methods for data collection from platforms

5.1. Introduction

Global changes affect the frequency of the occurrence of extreme meteorological events which may be particularly detrimental to coastal areas and endanger the sustainability of marine and coastal environments in supporting human needs [(Bondesan, et al. 1995; Nicholls, et al, 1999; Ulses, et al, 2008; Rabalais, et al. 2009; Lipizer, et al, 2012; Appiotti, et al, 2014], thus leading to a growth in treaties and conventions to improve observational and prediction capabilities for various ecosystems from local to global scales [Baüer et al, 2006; Kintisch 2007]. A significant growth in coastal and ocean observing system planning (e.g. US Integrated Ocean Observing System (IOOS), Global Ocean Observing System (GOOS), IOC of UNESCO Subcommission for the Caribbean and Adjacent Regions (IOCARIBE), Intra-Americas Sea Global Ocean Observing System (IAS-GOOS), etc.) has resulted from this effort, improving the level of detection and forecast of climatic changes [Seim, et al, 2002). Moreover, the advent of real-time observations using various platforms, expanded coordinated observations, and cooperative efforts from federal governments, universities, industries and various agencies has improved the prognostic calculations of important physical, chemical and biological mechanisms in oceanic and coastal regimes.

The current section of the e-handbook is dedicated to fixed oceanographic platforms falling under the standard name of **moorings**: a tethered collection of oceanographic instruments at a fixed location that may include seafloor, mid-water and surface components. The above definition is taken from the L06 SeaDataNet Vocabulary (SEAVOX PLATFORM CATEGORIES https://vocab.seadatanet.org/v_bodc_vocab_v2/search.asp?lib=L06).

This section is an extension of the comprehensive document on best practices done as part of the FIXO3 Project Platform Description [Coppola, et al, 2016].

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

5.2. Platform overview

5.2.1. Purpose

The requirement for continuous and effective monitoring of marine processes introduces the need for systems that enable experts to obtain the requested information as validly and promptly as possible. Repeated meteorological and oceanographic measurements at specific fixed locations of the oceans allow us to continuously observe the marine environment, understand the mechanisms and processes of the ecosystem and atmosphere-ocean interactions, record changes, calibrate and verify forecast models. In recent years, efforts have been made to install multi-parameter marine observatories in various parts of the globe under the coordination of the international OceanSITES programme (www.oceansites.org). Marine multiparametric observatories are perhaps the only solution to such a problem as alternative methods, such as satellite remote sensing, are limited to surface temperature measurements, sea colour analysis for biological parameters such as chlorophyll, surface estimation and sea level. The reliability of these measurements always depends on the ability of any mathematical algorithm to process the electromagnetic spectrum provided by the satellites to output the measurement and is not always acceptable. A typical example is the recent announcement by NASA to stop reporting the sea level from the Envisat satellite because systematically processed measurements showed a steady decline in ocean levels from 2009 to date (ESA European Space Agency website 7 July 2013). The remote sensing methods also have many other limitations; the spatial resolution is too low for any process studies, observed variables do not contain all necessary parameters and the time resolution, especially on polar-orbiting satellites is too low for analysing diurnal variations which are key phenomena in marine ecosystem functioning. Furthermore, the satellite measurements are inadequate is the inability to measure the entire column. Thus, the very parametric observatories are the only reliable alternative for the continuous recording of the necessary parameters directly with specific instruments for each parameter and many times from the surface to the bottom.

5.2.2. Description

Coastal buoys and pylons

Floating observatories officially started being used for the first time in the fifties (1951). Their use aimed initially to extend the measurements to the coastal zone and the high seas, giving improved meteorological measurements to optimize the awareness of the weather conditions related to aviation with seaplanes, those information until then were given only by ships.

Floating observatories used a combination of ropes and chains and suitable underwater buoyancy elements with a dead weight at the end to anchor them. Over the years and the growing need for more and different measurements, floating measuring stations of this type (Figure 5-1) began to grow in numbers depending on the instruments they carry and the state of the sea in which they operate, starting from sizes 1.5 up to 12 metres maximum in diameter and operating at depths ranging from 20 to 5000 metres. Their shape is usually disc-shaped and the material that offers buoyancy is typically polypropylene. The load-bearing structure for attaching the buoyancy units, the meteorological and surface measuring instruments as well as the supporting equipment is galvanised steel, sea aluminium or a combination (more common).

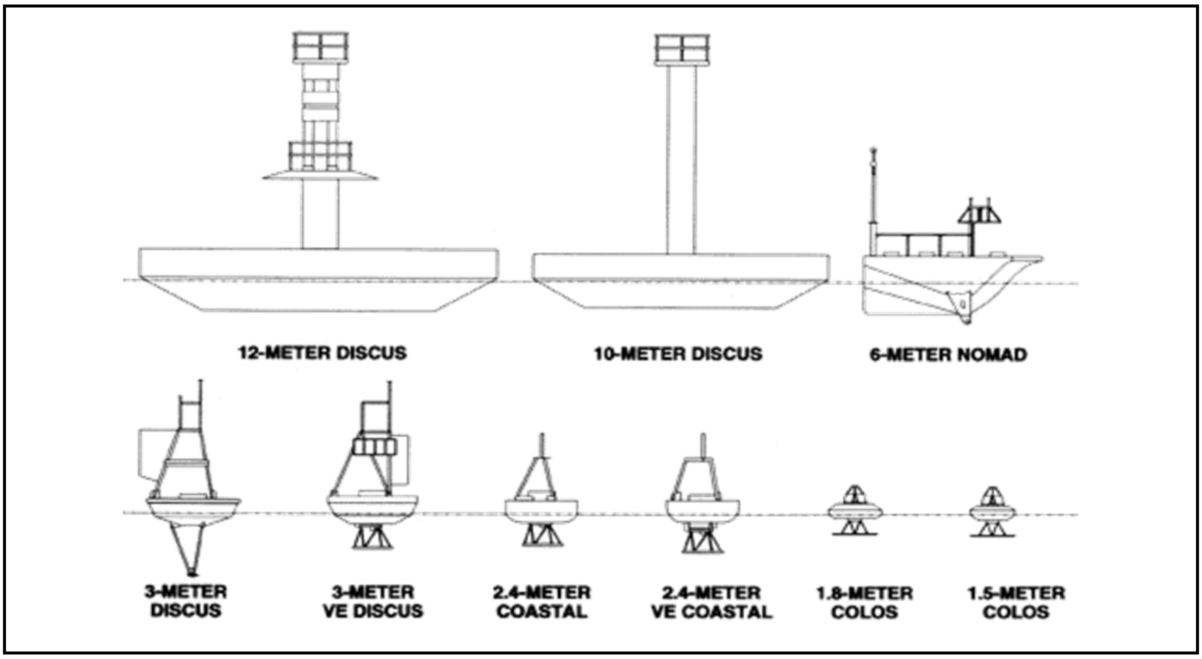

Figure 5-1 :Typical diagrams of floating measuring buoys.

Typically such stations have a mast of 3 - 10 metres where the meteorological instruments are attached measuring the speed and direction of the air, the atmospheric temperature and pressure, rainfall, humidity, incident solar radiation etc. In addition to the meteorological instruments, telecommunication antennas, signal lamps, radar reflectors (usually passive) and lightning rods are attached to the same mast. In the main body of the floating station the oceanographic instruments are attached, usually measuring marine surface conductivity, temperature, speed and direction of currents at various depths (usually up to 80 metres), dissolved oxygen, dissolved carbon dioxide, sea surface wave spectrum, etc.

Under the float and most often on the anchoring (mooring) line additional instruments for measuring physicochemical parameters are attached, such as conductivity, temperature, pressure, turbidity, chlorophyll type A, radiation detectors etc. These instruments can reach the end of the euphotic zone or continue along the length of the mooring line even down to to the seabed.

The measuring instruments of each station depend on its size, its energy efficiency and the place where it is placed. Usually the energy required for the operation of the station is provided by electric accumulators and an array of solar photovoltaic cells assisted by a wind turbine. Larger offshore stations with long maintenance period (> 1 year) or placed in areas with little sunshine additionally use fuel cells or even electric generators with internal combustion engines.

The data collected by the measuring instruments as well as the information on the operational status of the measuring station are stored locally and sent via satellite or cellular network to a receiving station on land where the measurements are analyzed and filtered with the ultimate aim of disseminating the data to the interested scientists or provide usable information to stakeholders and the general public.

The whole process is performed to a large extent in an automated way for the immediate use of the data with a period ranging from every 15 seconds to every three days or more depending on the data. Typically stations that transmit semi real time meteorological and oceanographic measurements such as those mentioned above do so with a period of one or three hours. At the moment in Greece there are four such coastal fixed floating measuring stations that are part of the POSEIDON system in the framework of operational oceanography at the Hellenic Centre for Marine Research (HCMR).

Cabled underwater systems

Cabled underwater systems are one of the future technologies that can contribute to real progress in coastal ecological research once their technological development is sufficiently advanced. The possibility of a continuous interactive “presence” in environmentally (e.g. weather-related or geographically) difficult focus regions, such as the Polar regions or the North Sea, makes this technology highly valuable for answering Earth system questions.
Cabled coastal observatories are often seen as future-oriented marine technology that enables science to conduct observational and experimental studies underwater year-round, independent of physical accessibility to the target area. Additionally, the availability of (unrestricted) electricity and an Internet connection under water allows the operation of complex experimental setups and sensor systems for longer periods of time, thus creating a kind of laboratory beneath the water. After successful operation for several decades in the terrestrial and atmospheric research field, remote controlled observatory technology finally also enables marine scientists to take advantage of the rapidly developing communication technology. The continuous operation of two cabled observatories in the southern North Sea and off the Svalbard coast since 2012 shows that even highly complex sensor systems, such as stereo-optical cameras, video plankton recorders or systems for measuring the marine carbonate system, can be successfully operated remotely year-round facilitating continuous scientific access to areas that are difficult to reach, such as the polar seas or the North Sea. Experience also shows, however, that the challenges of operating a cabled coastal observatory go far beyond the provision of electricity and network connection under water.
The two COSYNA Underwater Node Systems are operated at two sites that differ significantly in terms of climatic and hydrodynamic conditions, but exhibit a remarkable similarity in terms of biota composition with respect to the fish and macroinvertebrate species present in both areas. The “COSYNA-Helgoland” Observatory is located about 500m north of the island of Helgoland, at a depth of approx. 10m, at the AWI (Alfred

Wegener Institute) underwater experimental field “Margate”. The COSYNA-AWIPEV Observatory is located in the Kongsfjorden Arctic fjord system, at 10m water depth on the west coast of Spitsbergen. Similar to moorings or other autonomous sensors, cabled underwater observatories offer the opportunity for temporal high-resolution long-term measurements in areas where it is difficult to perform manual sampling all year round. In addition, automated sensors can form the backbone of intensive measurement campaigns so that discrete sampling, for example, with (costly) research vessels can concentrate on collecting non-automatically measurable variables. In addition to moorings and autonomous

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sensors, cabled observatories also allow the use of highly complex sensors that need frequent human interaction for reliable operation – even in remote areas where access is limited.

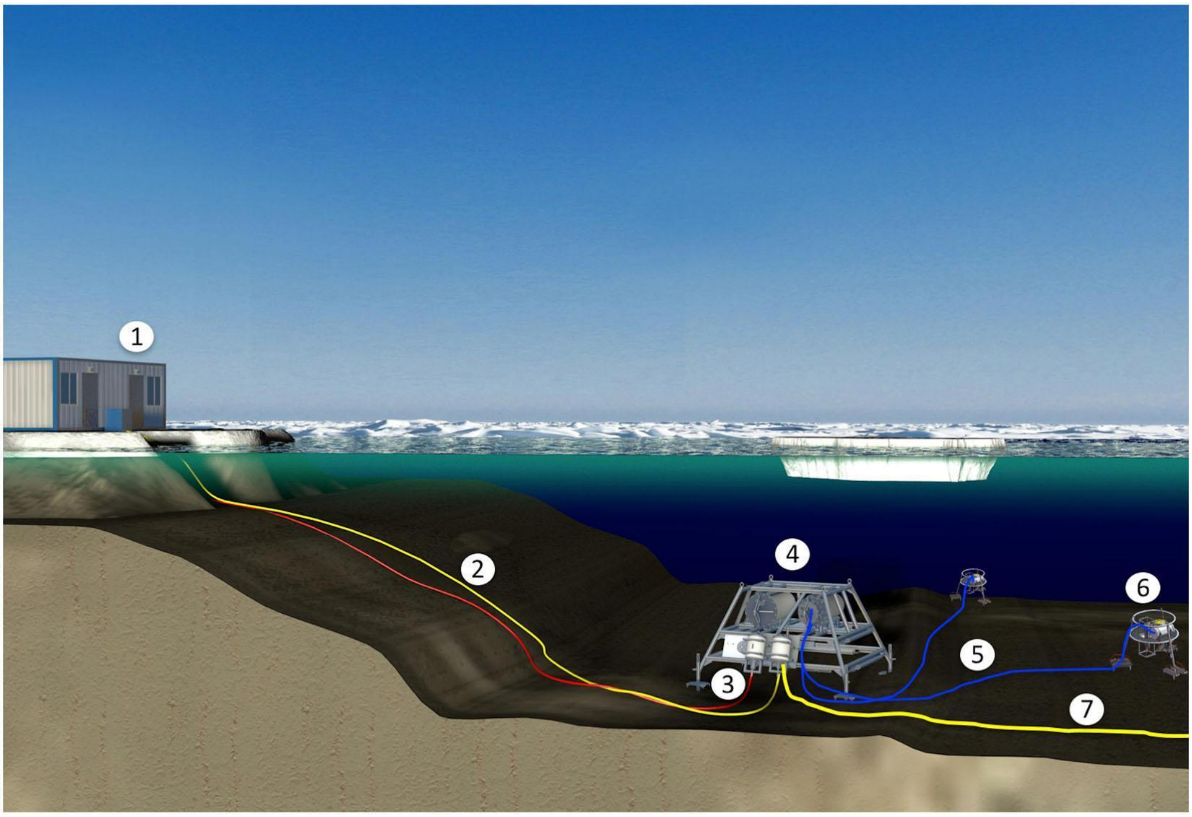


Figure 5-2. Basic deployment concept of the COSYNA Underwater Node System: **(1)** land station, **(2)** submarine cable (1000V), **(3)** breakout box, **(4)** underwater node, **(5)** Power (48V)/TCP-IP hybrid cable, **(6)** sensor carrier (lander), and **(7)** submarine cable (1000V) to daisy chained second node. The maximum distance from the land station to the first node respectively among the daisy chained second and third nodes is 10 km. Maximum water depth is 300 m. See text for a detailed description of the single components.

Coastal profiling systems

Coastal profiling systems can help to integrate indispensable information on water column characteristics in coastal areas [Fischer, et al, 2019]. The majority of the systems are research prototypes, quite rough to operate and very different from one to the other. It explains why documentation for coastal profilers is not well developed and available. The types of coastal profiles used within the JERICO network are:

- The coastal ARVOR floats are specifically adapted from conventional open sea profilers to be operational in the coastal area. The objective of the coastal float is to perform profiles between "stationary" phases. The "stationary" phases are obtained when the float is landed on the seafloor. The scientific payload embedded on coastal profiling floats are up to now, quite limited due to the small size of such floats.

- Buoy profilers deployed on the sea surface and automatically raise and lower oceanographic instruments at pre-programmed intervals using an onboard winch. A typical buoy profiler consists of a buoyant housing that contains the winch, wire drum, batteries, and communications equipment. For example, the EOL buoy that raises and lowers a SBE CTD from the surface down to a predefined depth.

- Bottom-mounted profilers also use an automatic winch but unlike buoy profilers the winch is anchored on the bottom and is used to raise oceanographic instruments embedded in a buoyant housing. Bottom-mounted profilers under development in the JERICO network are the IFREMER Mastodon and the IMR YoYo system. The Mastodon system is a passive water column profiler (chains of static sensors) that provide profiles compiled from measurements from discrete depths above the seafloor while the YoYo is an active automated system that continuously profiles a specified portion of the water column above the seafloor.

- As part of the JERICO-S3 North Sea Pilot Supersite implementation, and in collaboration with the AWI Dive Center in Helgoland, the Helmholtz-Zentrum Hereon is maintaining a long-term deployment of the Helgoland Underwater Observatory (HUWO). The HUWO's main component is a lander structure, which can be programmed to move vertically through the water column with remotely controlled winches, utilizing the buoyancy of floats attached to its outer edges for the upward movement, and straps connected to the winch and anchored to a base on the seafloor to move downward. Cameras and sensors are mounted on this vertical profiler. Utilizing this set-up, a continuous time series of plankton and particle biodiversity, biomass, and behaviour in the North Sea near Helgoland is currently being collected. All Images are sent in real-time to shore and are classified automatically using AI and different machine learning approaches. These observations allow conclusions regarding the biodiversity, impact of climate change, ecosystem productivity and the occurrence of invasive species at the PSS. The HUWO is located in the Margate experimental field at a water depth of up to 10m. Additional physical, meteorological and chemical data collected in the same area can be closely associated with data collected at the HUWO. A live-feed of some of the physical, chemical and meteorological data collected at this site can be found as an online stream.

One challenge met within the European coastal seas areas is the seasonal ice cover, which prevents the use of surface buoys for year-round observations. Seasonal sea ice cover exists in ocean areas near Svalbard and in the Baltic Sea. In the Baltic Sea, there are two Flydog's **cabled underwater profilers** installed, one next to Keri Island in Estonia (depth

100m, operated by TTU) and another next to Utö Island in Finland (depth 76m, operated by FMI). These systems are connected to the shore via (DC) power and data cable providing real-time internet connection to the system. The system is designed so that the control frame floats above the seabed and can be surfaced by opening the acoustic releasers attaching the profiler to the anchor. The sensors in the float are built around a standard CTD and include normal observations like salinity, temperature, oxygen and chlorophyll. Additional sensors for e.g. cyanobacteria can be added. The observations are supported by a stand-alone ADCP (Acoustic Doppler Current Profiler) providing information on underwater currents and sea surface waves. With a suitable construction and extra batteries, the ADCP can operate continuously for more than a year.

As the seasonal sea ice excludes the use of surface buoys, the observations are often supported by a nearby coastal meteorological station providing observations of basic meteorological variables including air temperature and humidity, wind speed and direction, solar radiation and other relevant variables. The supporting land stations can also include additional marine observations like sea ice cover, lidars, sea-atmosphere interface gas fluxes, in-situ imaging instrumentation and biogeochemical observations [Laakso, et al, 2018, Honkanen, et al, 2021; Kraft, et al, 2021]

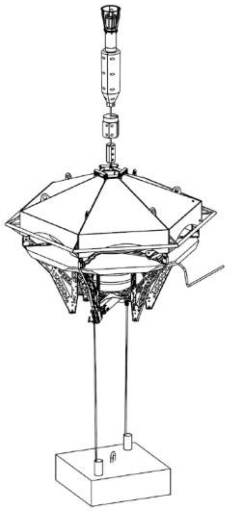


Figure 5-3: Flydog Solutions Salla cabled profiler consists of an anchor, acoustic releasers, measurement unit inside the float and a CTD float attached to a profiling cable. The measurement unit is connected to a land cable (cable pointing to the right) providing both data connection and power for the system.

Table 5-1: Specifications and technologies used for the operation of coastal profilers

System	Deployment	Power	Fouling	Telemetry	Maintenance
Buoy Profiler	Deployed at the surface but exposed to winds, waves, floating objects and marine traffic.	The buoy is usually equipped with solar panels, wind generators and can operate for a long period	The surface immersed components are exposed to high fouling pressure.	The surface components can provide bidirectional telemetry as fixed stations.	All the modules of the system apart the mooring line are accessible for field maintenance.

Bottom mounted Profiler	Deployed at the sea bottom and secured from surface exposure but vulnerable to fishing and anchoring activities.	The winch equipment consumes large amounts of energy. To be deployed for a long period requires cable to shore connection	The oceanographic payload can be parked between profiles below the photic zone so the fouling effect is minimised.	The real time communication with the system is limited. If there is no cable up to the surface or the shore the data are obtained only if the system comes to the sea surface between profiles or after recovery.	The system needs to be recovered totally for full maintenance. An identical spare payload setup allows changing the sensors without the need for lifting the whole system.
ARVOR Argo Coastal Profilers	Deployed at sea from a (small) boat. Vulnerable to fishing activities. Risk of beaching according to currents.	Limited embedded power and very constrained by floatability of the float that need to be very well adjusted.	The oceanographic payload can be parked between profiles below the photic zone so the fouling effect is minimized. And, the deployment duration is often limited to several weeks.	Data transfer and M2M communication can be achieved between profiles when the float is on surface. Satellite communication is used.	No maintenance during deployment. The float can be and refitted if recovered.

5.3. Detailed platform design

5.3.1. Design and functionality of platform

In Europe, but also worldwide, many types of moorings have been deployed in coastal waters but with diverse designs, maintenance and protection procedures, attending to different requirements and limitations. Despite its heterogeneity fixed platforms show the following common elements:

- Sensors: Responsible for measuring the chosen parameters.
- Data-logger: Responsible for management, synchronisation and data storage.
- Power supply: Responsible for the power supply to the rest of elements.
- Data transmission: Responsible for sending data to the land receiving station.

These four elements can be combined in different ways, giving different designs, and will have specific characteristics addressing the location and observational needs. Considering these aspects a **"Fit for Purpose"** approach is used. Rather than using standardized equipment, each design on a mooring is optimized for a particular location and measuring requirement. The heterogeneity on fixed stations architecture obtained as result of this approach, should not affect the comparability between different stations. The data comparability, based on standard sensor maintenance, references and quality control methods can be considered as the key element.

The selection of the location where the platform will be installed is the first and probably the most important decision to be taken in the platform life cycle. Representativeness of the platform, sustainability and convenience for maintenance tasks would be the main aspects to deal with during the selection of the location

A typical example of coastal buoys are SEAWATCH and WAVESCAN buoys, manufactured in Norway by Fugro OCEANOR AS, and used in coastal networks operated in Greece, Portugal or Spain (respectively by HCMR, IH, Puertos del Estado and AZTI)

Figure 5-4: Picture of the SEAWATCH and wavescan type of buoy, respectively

The following list of sensors and equipment are the full set of instrumentation used in the Greek Poseidon network. The set-up varies in accordance to the deployment site.

Internal components

These components reside inside the dry metal container of the buoy.

- WAVESENSE (mini computer, data logger, wave sensor)
- Inmarsat C transceiver
- GPS receiver

- Magnetic compass
- Internal air pressure sensor
- External air pressure sensor
- Sea Bird electronics modem
- Water leakage sensor

External components

These components reside outside the dry metal container.

Above sea level

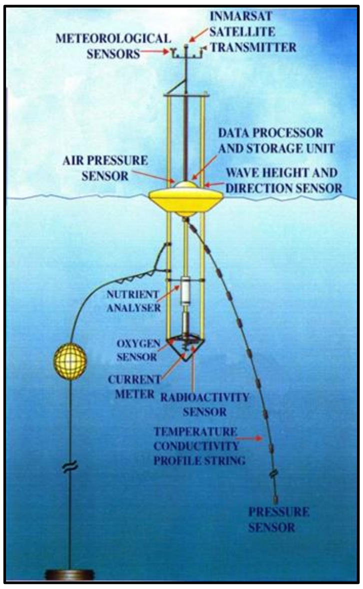
- Air temperature sensor

- Wind speed and direction sensor
- Humidity sensor
- Precipitation sensor (Depending on deployment position)
- Radiance sensor (Depending on deployment position)
- Radiometer (Depending on deployment position)
- Pyranometer (Depending on deployment position)

Below sea level

- Water current speed and direction sensor
- Water conductivity and temperature sensor
- Irradiance sensor (Depending on deployment position)
- Current profiler (Depending on deployment position)
- Dissolved CO2 sensor (Depending on deployment position)
- PAL sensor (Depending on deployment position)
- CTD sensor (Depending on deployment position)
- Turbidity sensor (Depending on deployment position)
- Dissolved oxygen sensor (Depending on deployment position)
- Fluorometer sensor (Depending on deployment position)
- PAR underwater radiation sensor (Depending on deployment position)
- Acoustic release unit
- Acoustic modem (Depending on deployment position)

The deployment depth and distance from coastline may vary, but two typical configurations are as follows:



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Parameter	Depths measured (m)	Sensor(s) used	Accuracy
Wind speed/dir.,	Surface	Young 04106	1m/sec, 10 deg
Air Pressure,	Surface	Vaisala PTB 220A	-+0.15hPa
Air temperature,	Surface	Omega	-+0.1oC
Wave Height, direction, period	Surface	Seatex MRU	0.05m, 2 deg, 0.15 sec
SST, SSS surface,	Surface (1m)	Aanderaa 3919A	-+0.1 oC, 0.05 mS/cm
Currents	Surface (1m)	Nortek Aquadopp 400 kHz	Sp: -+0.5 cm/sec Dir: -+2 deg

Figure 5-5:. Schematic drawing and typical instrumentation for a SEAWATCH coastal buoy

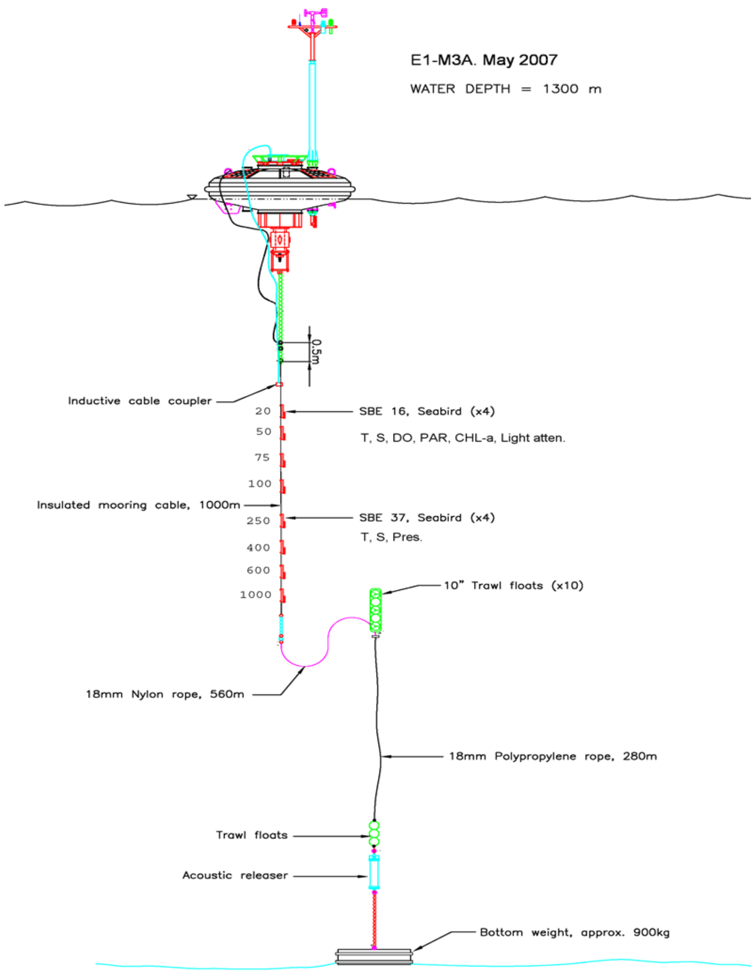

Figure 5-6: Schematic drawing and typical instrumentation for a WAVESCAN buoy

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5.3.2. Maintenance

The oceanographic buoys are support constructions for instruments and sensors that remain in the open seas for many months. In such a working environment a number of reasons can lead to a reduced quality of measurements from the sensors of the instrumentation as well as deterioration of the supporting structure and mooring line. The main reasons for the deterioration of instrumentation and the supporting buoy construction are:

Sea water is responsible for increased galvanic corrosion issues on all metallic parts (buoy and mooring system) leading to their progressive destruction which inevitably increases dramatically high the risk of loss of the deployed station.

Wind is responsible for fine dust deposition that in conjunction with breaking waves and sea water spray, create films of dust and salt that are deposited on all unprotected surfaces such as wind sensor blades, solar panels, connectors etc.

Waves are responsible for the mechanical fatigue of the structure and mooring line that for prolonged periods of time can even lead to bolts coming loose and bending of the supporting frame of the buoy.

Bio-fouling is responsible for degraded measurements on all submerged instruments that use optical or water flow based sensing procedures.

It is therefore immediately understood that maintenance is of paramount importance to allow for a reliable and optimally functional system.

According to the manufacturer the buoy and their mooring line should be maintained at least once per six (6) months.

The maintenance procedures described below refer to all types of the POSEIDON network buoys with exceptions when noted.

The survey preparation requires the booking of a ship with a crane and preferably a Π or A frame capable of lifting at least 2000kg. and winches able to pull 5000kg. and hold at least 3000 metres of 16mm ⌀ wire rope.

The maintenance survey could be divided in three (3) phases. The first is before going onboard the ship, the second while on the ship and the third when coming back from the survey.

During maintenance it is advised to keep track of all works, repair and solutions on three types of documents. In addition, photographs could complement and add to the information after recovery, during maintenance and before deployment.

1) Maintenance surveys Log book containing
    a) Buoy Deploys/Recoveries (Location, Time, etc.)
    b) Problems/solutions/Modifications
    c) Mooring line details
    d) Photographs

2) Accidents Log book containing
    a) Location, Time of event.
    b) Identification of lost equipment (serial numbers, etc.)
    c) Circumstances/reasons for the event.
    d) Photographs
3) Check lists
4) Calibration documents
5) Factory manuals, documents

Maintenance survey preparation (Phase 1)

1. Preparation of the mooring lines and anchoring weights and components as anodes, swivels and shackles.
2. Verification of the release codes for the releaser unit.
3. Packing of all instruments and consumables and itemization inside proper boxes and/or cages.

Maintenance survey (Phase 2)

1. Verification that all needed equipment are onboard the ship. Inspection of the buoys and equipment for obvious damages during transport.
2. Connection with the buoy via the serial link cable and verification that all the processes are loaded and running.
3. Verification of the transmission link (especially Inmarsat C).
4. Filling of the buoy instrument container with Nitrogen to avoid possible explosive mixtures of air while deployed.
5. Verification of the buoy's configuration regarding:
    - Parameters names, units
    - Parameters coefficients
    - Parameters resolution transmitted (set up ranges, bits etc.)
6. Inspection of all instruments and sensors to be adjusted on the mooring.
7. Recording of all necessary information for the update of POSEIDON MetaData DB such as S/N, sensor type-model, deployment depth, batteries status, etc. for every instrument and sensor.
8. Buoy deployment.
9. Acquisition of reference measurements / samples (CTD cast, Rosette sampling, etc)

Upon the recovery of a deployed buoy in addition to the following steps mentioned above the following are also performed (on the ship).

1. Observation for any obvious damages to external parts especially solar panels.
2. Detachment of external instruments for cleaning, data upload, maintenance and re-configuration.
3. Removal of used batteries and replacement with new.
4. Cleansing of the buoy with a high pressure water pump and removal of any sea – shells that may have grown on the frame and surfaces.
5. Careful opening of one of the release valves on the lid waiting at least for ten (10) minutes. The lead acid batteries are vented but danger of explosive mixtures inside the container are never zero.

6. Verification of the connectors on the lid against damage and corrosion.
7. Inspection of the instrument container from the inside for any visible clues of water/moisture leakage.
8. Verification of the output of every solar panel by usage of the wattmeter instrument
9. Application of bio-fouling paint (copper, tin free)
10. Re-insertion of all instrumentation back at their appropriate places.
11. Downloading of data files from the buoy to a folder on the field laptop
12. Downloading of the old configuration files and creation of the new configuration files for the buoy deployment.
13. Performance tests for at least three data acquisition cycles.
14. If all is ok (including the batteries being fully charged), proceed with the deployment of the buoy.
15. Acquisition of reference measurements / samples (CTD cast, Rosette sampling, etc)

In the case of a buoy with an inductive cable mooring line, in addition to the steps outlined above the following must also be carried out.

1. Laying of a large loop of the first 100 metres of the inductive cable on the deck of the ship.
2. Short circuit the inductive cable by connecting the exposed ends with a wire (beginning with end).
3. Attachment of all SBE instruments on the inductive cable spaced at least 50 cm from each other. The ferrite end of the instrument must be completely closed.
4. Check the inductive cable coupler with a multimeter for any discontinuities.
5. Verification that in the configuration files the identifier numbers are the same as the ones the instruments have.
6. Verification of the measurements via the software of the buoy, throughout the duration of the testing cycles
7. Verification of the depth markings on the inductive cable to be in accordance to the instruments identification number and placement of the first four sensors (up to 100 m depth). The rest of the sensors (up to 1000 metres) are attached on the mooring line during the deployment procedure.

Figure 5-7: The buoy with the first 100 metres of inductive cable arranged at the stern of the ship before deployment.

Maintenance survey post procedures (Phase 3)
After the end of the survey a number of issues are addressed

1. Cleaning of all equipment and tools to prevent corrosion.

2. Recording of all recovered instruments and preparation for service/calibration according to the manufacturer instructions.
3. Verification that the data is received and displayed properly.
4. Contacting the meta-data team.

5.3.3. Deployment and recovery

The deployment and recovery of marine multiparametric observatories require specific equipment and depends mainly on the length of the mooring line, the maximum depth of the observatory, the number of instruments it carries, the weight of its load bearing construction and the weight of the anchoring ballast to keep it in place.
The best way to deploy and maintain such observatories that can easily weigh more than 1500 kg with mooring line length up to 5000m is by the use of special oceanographic research vessels. These vessels have all the necessary equipment (CTD-rosette, precise positioning systems (e.g. a ship dynamic positioning system), dry, wet laboratories, etc) and trained personnel to perform the necessary operations with safety and efficiency.
Deployment-recovery procedures should start with the definition of a complete Field Service Plan (FSP) which defines the nature of the work to be done and include the necessary equipment lists, specific mooring diagrams, and logistics requirements. FSP should normally be prepared in advance of a maintenance mission. FSP or similar documents must also be communicated to relevant Marine Authorities in order to obtain any required permissions for

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the operations. Once on board the survey vessel, the FPS should be illustrated to all scientific and technical personnel on board, to help assign the role of each person involved in the operations.
On such vessels the operations manager and/or the chief scientist with the help of highly trained personnel address the following :

- Check that all mooring components and support equipment loaded aboard the ship
- Provide service, repairs, or adjustments to the buoy, mooring, or payload
- Complete a thorough buoy inspection prior to the ship getting underway to assure the seaworthiness of the buoy;
- Plan optimal deployment/recovery techniques by collaborating with the captain of the vessel to minimize the risk of damage both to the science equipment as well as to the ship itself, keeping at all times personnel safety a priority.
- Prepare a complete and accurate report of the operation including all pertinent test data and configuration control information
- Keep accurate documentation on the deployed mooring configuration, and any changes made to existing moorings

Seabed observatories additionally need the aid of special remote operated vehicles (ROV) for underwater equipment inspection, placing and removal. Very shallow waters (max ~80 metre depth) can make use of divers as well. For cabled seabed observatories the use of a commercial cable ship is also necessary when it comes to installing and repairing the main cable and support . Especially during deployment for the cabled observatory, placing a scientific load in a precise position and direction requires that the lift line and ROV umbilical control line be in the water at the same time. This requires special consideration as some

ship and ROV operating companies and ships captains do not allow it, due to the high probability of the two lines getting entangled.
According to the FixO3 best practices handbook [Coppola, et al, 2016] the following generic steps should be addressed:

- **Deployment procedure**

1. Preparation and review of all the instrument parts including brackets and anchoring parts and boxing for safety transportation to the vessel. This should also include all necessary tools and chemicals used during the deployment. They should be ready and organized so that there is no risk of mixing e.g. chemicals. When deploying cabled profilers, the connectors need to be cleaned on the ship deck quickly. If the wrong chemical is around, serious damages to connectors may take place.
2. Deployment procedures should also include plan B and C i.e. if weather changes and the deployment procedures have to be stopped, or if some problems previously unknown are found.
3. Installation briefing with divers team or ROV pilots, vessel captain and instrument Responsible technicians. Deployment procedures should also include plan B and C i.e. if weather changes and the deployment procedures have to be stopped, or if some problems previously unknown are found.
4. Instrument and data receiving system commissioning should be coordinated with the shore station team to verify correct assembly.

   After the deployment the instrument will be included in the observatory maintenance

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

programme that should include continuous monitoring of instrument environment (internal temperature and humidity, supplied voltage, consumed current, etc.), regular visual inspections and manual cleaning if required.

- **Recovery procedure**

1. Platform and instrument software shutting down and electrical switch off.
2. Platform and instrument recuperation by vessel and diving/ROV team.
3. Graphical documentation of the equipment status as it gets.
4. Retrieval of data stored in the platform and instrument memory.
5. Operational check and after deployment calibration test.
6. Deep cleaning.
7. Packing and storage or return to the owner.
8. Write a report and archive the entire acquired data set.

More information can be found in the FixO3 Handbook of best practices [Coppola, et al, 2016]

5.3.4. Analyses of platform performance

At global level, OceanOPS (https://www.ocean-ops.org/) acts as a focal point for implementation and operation of relevant observing platforms. Metrics are displayed for the **Coastal/National Moored buoys** network under the umbrella of the Data Buoy Cooperation Panel (DBCP).
Available KPIs are:

- Activity
- Metadata Quality - Sensor
- Diversity (National)

Moreover, Key Performance Indicators (KPI) have been put in place by two main European Marine Data aggregators: the In Situ Thematic Assembly Centre (INSTAC) of the Copernicus Marine Service and the Physical component of the European Marine Observation and Data Network (EMODnet Physics).
INSTAC (http://www.marineinsitu.eu/monitoring/) is monitoring the data flow from the moorings network towards INSTAC products showing Near Real Time indicators like:

- Delay of arrival
- Number of platforms
- % Quality flags
- Number of files
- Number of providers

EMODnet Physics (https://www.emodnet-physics.eu/Map/Service/Indicators/) is for example providing:

- EMODnet Physics DB of the available In Situ Platforms: Indicator 2 - List of the platforms, providers supplying data, …
- EMODnet Physics DB of the active platforms: List of the platforms that delivered a dataset (during last 30 days)
- Volume of data in EMODnet Physics: Number of platforms per theme/parameter

- Use of data from EMODnet Physics: Amount of Downloaded Viewed parameters (per theme)
- EMODnet Physics use of data - most requested platforms: List of the most viewed and downloaded platforms

Finally, recent work in JERICO-S3 has reported on the development of Key Platform Performance Indicators and Key Integration Performance Indicators for assessing in a harmonised way the performances of the observing platforms of the JERICO-RI, including the level of their integration at the network level [JERICO Deliverable D.5.3 (to be published).]

5.3.5. Uncertainties in observations

Platform-related factors can produce uncertainties in some of the variables observed in the different types of moorings. The mooring line of a buoy is the first possible source of uncertainties:

- A moored buoy will swing around the anchored position due to wind and currents. These movements will affect the eulerian measurements of current meters (single point and profilers).
- The mooring line could affect acoustic measurements performed by a downward-looking current profiler
- Wave measurements can be affected by limited capacity of movement in specific conditions, or simply by high current velocities [Pillai, et al., 2021]
- The shape of the mooring line will affect the depth of sensors (i.e. for temperature and conductivity measurements) installed along the line. A pressure sensor can be added to monitor this issue.
- Components of the mooring line like chains can generate noise in acoustic measurements.

Other platform-related sources of errors:

- Installation angle of optical sensors
- Reflections due to the frames
  Bottom-moored vs floating installations: sea level changes impact measurement depth, impact can be significant on a shallow measurement location.

5.3.6. Issues

For moorings to be installed in the coastal area, the location selection for deployment is the first and probably one the most critical decisions to be taken in the platform's life cycle. Representativeness of a location for observing goals will be sought. Appropriateness of the platform, sustainability and convenience for maintenance tasks would be the main aspects to deal with during the selection of the location. This includes trying to avoid conflicts with the uses of a specific marine area (fisheries, main navigation routes, etc). Finally, the process to obtain authorisation from competent authorities should be taken into account in the work time schedule.
Key questions to be answered in this initial phase are proposed in JERICO-FP7 D4.4 "Report on best practice in conducting operations and maintaining" [Petihakis, et al, 2012]

Another important issue is the weather-dependent aspect of the maintenance operations related to moorings. Limited metocean windows could highly impact the selection of needed resources (vessel and other equipment supply) and bring difficulties to fit with the maintenance plan.

Most buoys require ship support for installation, maintenance or recovery. Scheduling of ships and establishing mission profiles must take into account the cost of ship operations and availability of an appropriate vessel.

In coastal waters, security must be considered.

5.3.7. Mooring best practices and standards

Table 5-2: Mooring platform - best practices

Best Practice /title	refer in Annex I	Notes
Handbook of best practices for open ocean fixed observatories (FIXO3), DOI: https://doi.org/10.25607/OBP-1488, [Coppola, et al, 2016]	*26*	
Best Practices for the Ocean Moored Observatories, DOI: https://doi.org/10.3389/fmars.2018.00469, .[Venkatesan, et al 2016]	*34*	
Report on best practice in conducting operations and maintaining: D 4.4. (Version 1 - 27/02/2012). DOI:[10.13155/49741](https://doi.org/10.13155/49741) [Petihakis, et al, 2012]	*23*	

Standards

- Normal standard references for instruments
- Normally no-ISO standards used, except for occupational health and electricity (safety standards)

●

5.4. Sensors and integration into the platform

5.4.1. General Description

The payload of moorings usually allows the integration of a very high diversity of sensors in order to fit with the main observational objectives for the specific location. Depending on the type of moorings, they can include meteorological payloads, oceanographic payloads and/or sea-bed based payloads. Usually, the data transmission system is included in the aerial part. It is very difficult to define a standardized payload for all platforms because of the different goals and characteristics of the observatories which bring specific optimized designs.

In the list of sensors installed in JERICO observatories (see Table of sensors in Annex II), physical and biogeochemical instruments are more commonly integrated in floating structures or pylons. Limitations in the selection will come from the access to power and the loading capacity of the structure. That is why cabled observatories usually offer higher possibilities to integrate higher consuming systems like acoustic sensors or imagery.

5.4.2. Detailed description

Specific operations and maintenance protocols/manuals are generally provided by manufacturers and suppliers of each sensor. The needs can vary significantly depending on the type of sensor (acoustic, optical, chemical, …). However some common issues are identified.

Biofouling is a major problem shared among all maritime sectors employing submerged structures, with high impact on the maintenance procedures. It is particularly sensitive for the sensors of observational fixed platforms with potential high impact on data quality. So cleaning procedures are needed and depend on the oceanic sensors: Acoustic, conductivity, optical, Chemical… (Coppola et al: FIXO3 Handbook of best practices for open ocean fixed observatories: Table 2.1.3.2a: Maintenance procedures for oceanic sensors with cleaning methods). This specific topic has been tackled in different outputs from JERICO projects' and other networks' best practices (JERICO Deliverable 4.3 "Report on Biofouling Prevention Methods" [Faimeli, et al, 2019]; Handbook of best practices for open ocean fixed observatories (FIXO3) [Coppola, et al, 2016]. Research and developments to improve knowledge and mitigation solutions are currently also highly promoted by the marine renewable energy sector.

5.4.3. Sensor Calibration

Each sensor should be calibrated prior to and after the deployment, in order to ensure the accuracy of the measurements. The severity of the drift and required calibration scheme depends on the sensor type and the platform, especially biogeochemical sensors require frequent maintenance. As the cleaning and calibration of a sensor may be time-consuming, and possibly difficult offshore, a spare sensor might prove to be an effective solution for the maintenance of the system.

Depending on the sensor type, the calibration can be executed at an Institute's own laboratory facilities or at a certified external laboratory, or by the manufacturer. Dedicated staff experienced with calibration equipment may be required to perform the calibration, as is the case for the Winkler's method for the oxygen calibration. For the calibration of any sensor, the reference instrumentation, against which the sensor is compared, should be regularly validated at a certified laboratory.

5.4.4. Uncertainties in observations

A summary of correction methods used nowadays for physical and biogeochemical parameters is given by the FixO3 Handbook of best practices.

Table 5-3 Summary of correction methods as given by the FixO3 Handbook of best practices.

Variables	Drift	Correction methods	Reference
Pressure	very low	Offset and bias (P_{bias})	Karstensen, 2005
Temperature	very low	Offset (post-calibration)	Seabird manual, Karstensen, 2005
Conductivity	yes	Slope (bottles or post-calibration)	Seabird manual, Karstensen, 2005
Currents	low	Depth, local magnetic declination, sound speed	Karstensen, 2005
Dissolved Oxygen	Yes, low	Offset and gain	Argo oxygen manual, Takeshita et al. (2013)
Chl-a	yes	Offset with in situ data or satellite	
Nitrate	yes	Offset, pressure and drift	Johnson et al. (2013), Sakamoto et al. (2009)
pCO2	yes	Offset, pressure and drift	Atamanchuk et al. (2015)
pH	yes	no information yet	no information yet

The normal uncertainties in all observations:

- instrument accuracy and precision
- stability of calibrations

- Biofouling
- Uncertainty in reference instrumentation

The uncertainties relevant for specific observations:

- Community and environment dependence for Chl-a fluorescence measurements

5.4.5. Quality Assurance methods

QA is done normally following the recommendations given by the manufacturer, that is in accordance with the current knowledge of the sensor performance. Often additional challenges arise from biofouling as it may be difficult to estimate its magnitude and when the biofouling has begun. Thus, correcting data backward with e.g. linear approximations may not often be possible.

5.4.6. Issues

There are very few fixed stations and those are in different surroundings, so detailed general best practices may be challenging to create.
For moorings to be installed in the coastal area, the location selection for deployment is the first and probably one the most critical decisions to be taken in the platform's life cycle. Representativeness of a location for observing goals will be sought. Appropriateness of the platform, sustainability and convenience for maintenance tasks would be the main aspects to deal with during the selection of the location. This includes trying to avoid conflicts with the

uses of a specific marine area (fisheries, main navigation routes, etc). Finally, the process to obtain authorisation from competent authorities should be taken into account in the work time schedule.
Key questions to be answered in this initial phase are proposed in JERICO-FP7 D4.4 "Report on best practice in conducting operations and maintaining" [Petihakis, et al, 2012]

Another important issue is the weather-dependent aspect of the maintenance operations related to moorings. Limited metocean windows could highly impact the selection of needed resources (vessel and other equipment supply) and bring difficulties to fit with the maintenance plan.

5.4.7. Mooring Sensor best practices and standards

Table 5-4: Mooring - Sensor best practices

Best Practice /title	refer in Annex I	Notes
Handbook of best practices for open ocean fixed observatories. DOI: https://doi.org/10.25607/OBP-1488 [Coppola, et al, 2016]	*26*	
ICOS Ocean Station Labelling Step 2. v6.1 DOI: https://doi.org/10.18160/8SDC-K4FR [Skjelvan, et al, 2021	*35*	*Includes preliminary BP for marine carbonate observations and supporting observations.*
Instrumenting our oceans for better observation: a training course on a suite of biogeochemical sensors. DOI *http://dx.doi.org/10.25607/OBP-1041*, [IOCCP and BONUS INTEGRAL, 2019]	*36*	

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5.5. Data and Data Management Methods for data collection from Moorings

Work on data and data management for moorings was not planned in JERICO S3. In the future, this section may be updated to include: Description of data, data value chain,quality control and quality assurance, issues and best practices and standards.

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- IOCCP and BONUS INTEGRAL (2019) *Instrumenting our oceans for better observation: a training course on a suite of biogeochemical sensors June 10-June 19, 2019, Sven* Lovén Center for Marine Sciences (Kristineberg, Sweden). Available: https://classroom.oceanteacher.org/course/view.php?id=394 AND http://www.ioccp.org/2019-training-course?fbclid=IwAR22OXsWK_eZF1UyaUiEfUqJm-ISVATcAZuiDEYG3XQj1THSiqFuPJyVOR0 (Accessed 27 Jun 2022)
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6. PLATFORM 2: HIGH FREQUENCY (HF) RADAR

How to use this Handbook:

The Handbook is intended for a wide and diverse audience. It allows quick and easy access to the most appropriate sections. All readers are encouraged to read this introduction and the table below will help you decide which sections are likely to be most relevant to you.

Audience	*Recommended sections*
HFR Operational managers, M&O staff, HFR technicians, Coastal Ocean Observing System managers	6.2, 6.3 Platform Description
HFR Operational managers, M&O staff, HFR technicians, manufacturers	6.4 Sensor(s) and integration into the platform
Marine Data Managers, HFR data users, trainers, students	6.5 Data and Data Management Methods for data collection from platforms

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6.1. Introduction

This section of the Handbook is dedicated to High Frequency Radar and falls in the field of physical oceanography. It is addressed to a technical-scientific audience and deals with best practices in the management of High Frequency Radar (HFR) systems for ocean currents measurement. HF radars are coastal remote sensing instruments operating in the radio frequency band (3 to 30 MHz typically). Most of the recommendations concerning setup and operation of an HF radar are applicable in general (see next paragraph "purpose" for possible applications), however some of them and all the section 6.5 on data management are specifically provided for ocean currents retrieval.

This work builds, and updates with recent developments, on previous work carried out within the JERICO-NEXT Project. Its first aim is to consolidate and further disseminate recommendations among the JERICO RI community, helping HF Radar platform operators to reach the state-of-the-art in their systems management, sustaining new actors approaching HF radar technology, and promoting harmonization processes within the Research Infrastructure.

It is moreover a reference for the whole European HF radar community since it collects contributions from the EuroGOOS HF radar task team members.

Main references for this section are JERICO-NEXT Deliverable 2.4 "Report on Best Practice in the implementation and use of new systems in JERICO-RI. Part 1: HF-radar systems" [Horstmann, et al, 2019] and the derived paper "Best Practices on High Frequency Radar Deployment and Operation for Ocean Current Measurement" [Mantovani, et al, 2020]. They include a wide collection of other previous relevant peer reviewed publications and recommended practices, that will be recalled in this section.

Since the standard structure of this e-handbook is splitting "Platform description" section from "Sensor(s) and integration into the platform" section, when talking about platform description we will refer to the housing of the HFR's receiving and transmitting units, i.e. all the equipment (structure, power, data transmission, etc) needed to host an HF Radar device, while the sensor will be identified as the receiving and transmitting units themselves, plus the radio frequency (RF) antennas.

This separation is just a convention to comply with the main document structure shared with other platforms described here. For SeaDataNet vocabulary L06 (SeaVoX), HF Radar falls in the category of "coastal structure".

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6.2. Platform Overview

6.2.1. Purpose

HF-radar has shown to be a cost-efficient asset to monitor coastal regions at a range of up to 200 km, and therefore has become a favoured sensor to monitor coastal regions all over the world. Oceanographic HF-radars are mainly utilised to measure ocean surface current fields [Paduan and Rosenfeld, 1996; Gurgel, et al, 1999] for various applications such as search and rescue [Ullman, et al., 2006], oil spill monitoring [Abascal, et al., 2009], marine traffic information [Breivik and Sætra, 2001] or improvement as well as data assimilation of numerical circulation models [Paduan and Schulman, 2004; Barth, et al, 2008]. Further applications of the HF-radars include surface wave retrieval [Wyatt, 1990; Gurgel, et al., 2006], surface wind retrieval [Heron and Rose, 1986; Shen et al, 2012], as well as Tsunami detection [Lipa, et al, 2006; Gurgel, et al, 2011] and ship detection [Ponsford, et al, 2001; Maresca et al, 2014], of which the latter two are getting more and more popular. A recent review of science-based applications in the Mediterranean Sea involving HFR measurements in a multiplatform environment is given in [Reyes, et al, 2022] primarily focused on meeting end-user and science-driven requirements, addressing regional challenges in three main topics: i) maritime safety; ii) extreme hazards; iii) environmental transport process.

6.2.2. Description

The platform designed for hosting an HF Radar is basically a container located near to the shore and equipped with a minimum set of accessories that allow optimal operation conditions. It can be implemented as a fixed or mobile cabinet placed outdoors, as climate-controlled shelter or as a standard rack cabinet inside a room of a preexisting structure.

Figure 6-1: Example of rack cabinet hosting HFR units, computers and other accessories. Source: CNR HFR station in Liguria, Italy.

Recommended components are:

- reliable power source. Although it is possible to design off-grid HFR stations using other sources like photovoltaic or wind energy, such a solution is uncommon and quite expensive as the required power ranges from 300 W and 500 W, excluding air conditioning. The majority of the existing systems rely indeed on grid power. Uninterruptible power supplies are recommended for filtering out distortions and supplying electricity in case of short blackouts;
- dedicated electrical panel and grounding;
- air conditioning system, both for cooling/dehumidifying and for insulating the indoor environment from the outdoor salty air;
- onsite high capacity storage device for local data backup;
- devices for connection to a data communication network.

6.3. Detailed platform design

6.3.1. Design and functionality of platform

HF Radar platform is typically a fixed coastal structure intended for hosting a single HFR receiving and transmitting equipment, or even only the receiving or only the transmitting units if in bistatic configuration [Hardman, et al, 2020]. The platform can be relocatable if implemented in a small all-in-one shelter or trailer, however relocation in most cases implies new permissions and it's not straightforward. Measurements can be done only from a fixed location. After initial switch-on and setup, HFR stations operate automatically and continuously, with a limited need of on-site maintenance. Each system typically is optimized for operating within a range of 1 MHz around a specific central frequency, which has to be chosen in advance as it determines antennae size and placement, measurement range and resolution. Further details on the functionality are provided in the section 6.4 "Sensors and integration into platform".

- Enclosure and Air Conditioning

The electronics enclosure can be of different nature depending on the available space at the site, cooling, heating and dehumidifying requirements, the number of devices to be hosted, the need of protection against the sun, water, dust.
If a building is available, the enclosure can be located inside a room and a standard rack cabinet can be used. If required, an air conditioning system can be installed in the room.
If a building is not available, the following options can be chosen:

- weatherproof, climate-controlled shelter or trailer. This solution allows the operator to work in a small but still comfortable environment, and provides robust protection against natural hazards (weather, animals) and vandalisms. A trailer also has the advantage that it can be relocated with less effort.
- sealed, insulated, air-conditioned, enclosure with minimum fitting size for the electronics. Such compact solutions are less protected and may require specific and tailored air conditioning methods but are very flexible, e.g. can be deployed with very little space needed and relocated.

Figure 6-2: compact shelter for HFR station of LaMMA Consortium in Piombino (Italy). Source: SICOMAR Plus project T2.1.2 "production of new datasets from HFR networks".

- Data Acquisition

In most commercial HFRs the control of the electronics and data acquisition are performed by computers ranging from consumer PCs to entry level servers and running Mac OS X or Linux operating systems. They are typically provided in a bundle with the HF radar system and already pre-configured with all the needed control and processing software. They only need to be configured for a few parameters such as network settings, site-specific information, processing options. As the lifetime of the computer is typically much shorter than the electronics of the HF radar system, care should be taken with respect to compatibility between the manufacturer's software and newer operating systems.
A redundant external data storage system is recommended on-site as a backup for the data acquired and saved on the computer's disk.

- **Communication**

Connection to a data network is considered a prerequisite for any HFR installation. Besides being essential for near real time operational usage, remote communication with the HFR site via a broadband internet connection allows for redundant data backup and for a series of monitoring and management operations that significantly reduce the need of on-site maintenance.
Best results are achieved with a broadband wired connection (e.g xDSL, fiber) . If this option is not available, a mobile network data connection should be considered as a second option. With the fast development of broadband cellular networks (5G at the current date), data transfer and remote management of HFR stations are now easy tasks at almost no cost. Two or more SIM data cards from different mobile phone companies can be used simultaneously with specific modem-router devices, ensuring backup link and improved data rate. Industrial grade modem-router are strongly suggested as they provide wider operational range with temperature, better protection against humidity and dust, and some extremely useful software features, for instance the continuous check of the connection

status, a watchdog timer for automatic reboot in case of prolonged network disconnection, remote reboot via SMS, and MAC address filtering, amongst other options.
Wireless outdoor bridges can be used to link the remote site to a hardwired network connection if this is located over a distance of kilometres, in case of poor or unavailable mobile network connection at the site. Wireless outdoor bridges are implemented in several ways following the IEEE 802.11 recommendations and in most cases they rely on a point-to-point communication that requires free line-of-sight between two directional outdoor antennas.
Satellite internet should be considered as a potential alternative option for remote areas, although its performance is sensitive to weather conditions. Satellite internet companies should be contacted in advance to see if an intended HF radar site falls within their coverage area. Common satellite internet plans offer enough bandwidth and data volume at reasonable costs, allowing remote management and transfer of the most important data.
At minimum, an internet connection for the HF radar site needs to be able to transfer approximately 300 KB hourly (radial velocities files). In case of extremely slow connection, some HF radar systems offer the option of remote management using command line through SSH and/or control panels over HTTP, both requiring less bandwidth than screen sharing programs or graphical remote desktop access (e.g. VNC, Teamviewer).
Power surge protectors on ethernet data lines are strongly suggested to protect from lightning strikes and power surges. A protection should be placed also on the coaxial cable of a 3G/4G modem-router if an outdoor antenna is used.

- **Power Line Accessories and Uninterruptible Power Supply**

Once a suitable electrical power source is established, a remote HFR station may require additional solutions in order to minimize the need of maintenance on site due to power-related issues. They may include:

- a dedicated electrical panel and line, bypassing any pre-existing potentially problematic panels or electrical lines.
- a dedicated electrical grounding if not already existing or if not reliable (a test is highly recommended), and a separate grounding line for the lightning protection system.
- a circuit breaker with automatic reclosing capability, able to restore the power supply if the cause that triggers the breaker is only temporary.
- a smart power strip that can be switched on/off on schedule or by remote control e.g. if a hardware power reset is needed.

An uninterruptible power supply (UPS) should be used to provide near-instantaneous protection and power backup to the HFR system components. UPS acts as surge suppressor and ensures within certain limits stable sine wave (pure or simulated depending on the model) power through over-voltages and brownouts. UPS minimum requirements should include:

- an adequate output rating, that in most cases can be equal to 1 KW;
- an ethernet card and a website interface for remote configuration and monitoring; enough battery capacity to ensure 15 to 20 min of autonomy considering the maximum load, in order to properly shut down the sensitive equipment;
- the possibility to expand the battery pack if upgrade is needed;

- two or more outlet groups that can be managed separately.

UPS systems should be considered emergency power backup solutions meant to protect the most sensitive electronics components only.

- **Lightning Electromagnetic Pulse Protection**

Lightning is a frequent cause of damage in some geographical regions. The need for lightning electromagnetic pulse protection (LEMP) is also mentioned in [Cook et al., 2008]: "LEMP should be installed inline on any antenna (i.e. receiver and transmitter channels, GPS, communications) as a safety precaution for personnel and radar electronics. Lightning arrestors provide an alternate path to ground during a high voltage surge from lightning strike. There are a variety of designs, but typically the inline gas discharge types are used for RF communications, including HF radar". At least two levels of lightning protection are recommended for any system:

- At the antenna pole, as a protection of the transmission line.
- At the container/room cable inlet, as a protection to the electronic components.

Furthermore, [Cook, et al., 2008] indicates that different devices may require different specifications for lightning arrestors, for instance "the transmitter requires a lightning arrestor with a higher sparkover voltage than the receiver. Typically, common lightning arrestors (such as the Altelicon AL-NFNFB) come with gas tubes rated for 90V sparkover voltage. In this case, replacement gas tubes with 350V sparkover voltage can be purchased."
To mitigate this risk, special attention should be paid also to the design of the cable's path. Wrong cable placement could invalidate the LEMP when distances of protected and unprotected lines are too short, as the overvoltage is transmitted by electromagnetic induction bypassing the lightning arrestor, both on coaxial cables and power line.

6.3.2. Maintenance

First and more frequent kind of maintenance can be performed remotely. With an internet connection the system status as well as its data acquisition process and data themselves can be easily diagnosed and verified by means of web tools, email alerts, screen sharing applications.
As a complement, on-site inspection is unavoidable and is recommended on a regular biannual basis, in order to confirm the good status of the equipment and prevent issues, but also to perform scheduled actions such as data backup on external disk, UPS battery replacement, etc. Additional specific on-site inspections are recommended after a severe weather event.
Results of remote and on-site checkings should be included in periodic reports, for helping the operator to keep track of maintenance history.
Further details are provided in [Horstmann, at al., 2019] in chapter 4, they cover the use of software diagnostic tools and automatic alerts, and the recommended check-list during on-site inspections. The same document provides examples of tools for maintenance and inspection reports.

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

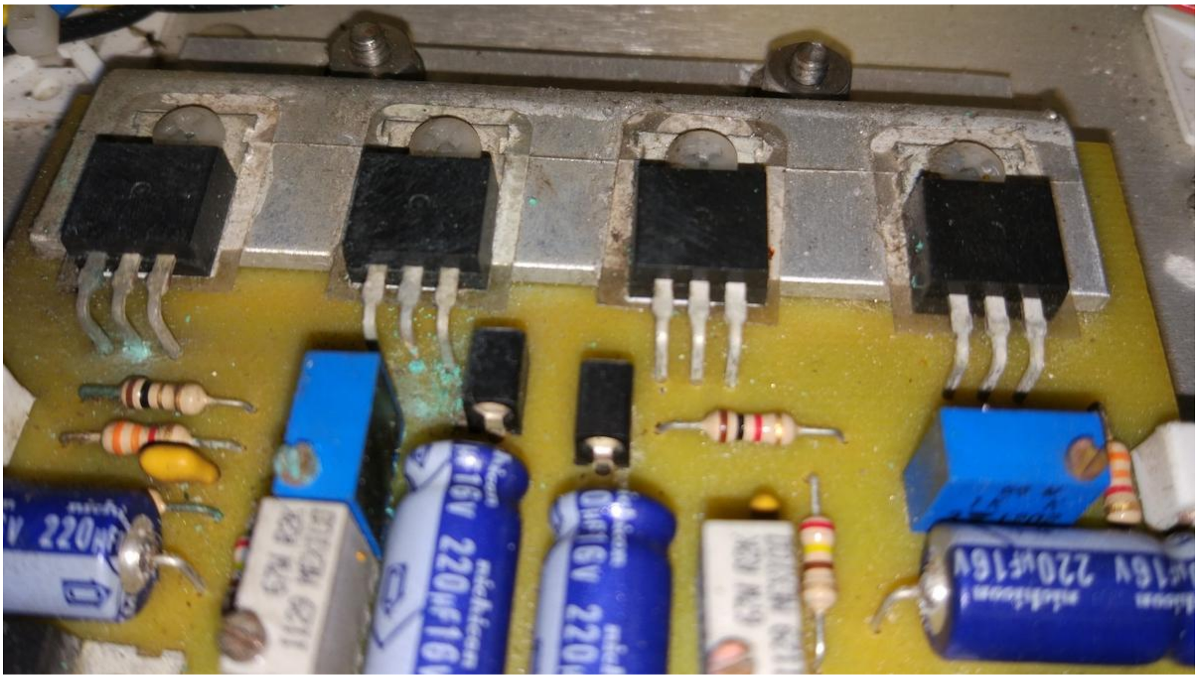

Figure 6-3: Corrosion of electronic components inside HF Radar transmitting unit. Source: CNR

6.3.3. Deployment and recovery

It is important, from both budget and planning perspectives, to consider the efforts required to source site permissions, site access, transmit licences, and last but not least, intended use of the data.

Complex regulations at the local, national and international level can delay the deployment of the HFR stations. In the worst case scenario, non-compliance with one of the several required permissions may lead to a failure in proceeding with the installation stage. A further important aspect in the planning phase is the determination of the location of each individual site as well as the site-to-site distance. The optimal location and site-to-site distance depends on the utilized system, frequency, salinity and shape of the coastline. This task becomes particularly difficult when the coastline does not offer easy access or any suitable infrastructures (e.g. buildings, roads, electrical power line). In case parameters such as sea state are required, the distance between sites has to be reduced accordingly [Wyatt, et al, 2006 and 2007].

- Site requirements

The optimal candidate site should match the following characteristics:

- located as close as possible to the shoreline but safe from waves and flooding
- protected from unauthorized human access and from damage caused by animals
- located in a flat or slightly sloping area allowing human access without hazards
- accessible by vehicles
- have enough space to accommodate antennas, electronics, and cables
- free of electrically conductive objects (e.g. metallic fences, poles and containers) in the antenna near-field
- free of radio interference at the operating frequency band

- free of obstacles limiting the field of view towards the ocean
- have nearby access to the electrical grid
- have stable and broadband internet connectivity, either wired or wireless

6.3.4. Analyses of platform performance

There are no defined indicators for platform performance in literature, if we are strictly considering the fixed structure hosting HFR units. This gap could be addressed in JERICO-S3 D5.3 “Report on the Key Platform Performance Indicators and Key Integration Performance Indicators” to be developed for the JERICO-RI.

6.3.5. Uncertainties in observations

Among the elements affecting the quality of the HF Radar data and the associated uncertainties [Kohut and Glenn, 2003], only few of them originate from a bad implementation of the HFR hosting platform, once the requirements for site selection are satisfied.
Overheating of the electronics may introduce a degradation of the signal to noise ratio, therefore suggested temperature thresholds should be monitored and respected with the help of air conditioning units.
Power-line disturbances may introduce noise in the radar spectral data, for this reason operators should apply appropriate power-line Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI) filters.

6.3.6. Issues

As all in situ instrumentation, also HF-radar suffers from the normal deterioration, in particular - but not only - of the outdoor components. Besides that, major damages have been experienced due to severe weather events inducing storm surge or lightning, which often lead to electrical damages or antennae breakage. Another not to be underestimated source of damage results from animals (in particular to cables) or human vandalism.
For ocean current measurements, which is the primary and most mature output of HF radars, two or more stations are needed looking at the same ocean patch, because one single HFR station can only retrieve the component of the velocity along the radial direction with respect to its look direction. For this reason, once two or more HFR platforms are in place, relative positions must be maintained for optimal performance, and therefore moving one of them, should it be possible, will have a negative effect on the performance of neighbouring stations.

6.3.7. HF Radar Platform best practices and standards

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Table 6-1: HF Radar - Platform best practices

Best Practice /title	refer in Annex I	Notes
Report on Best Practice in the implementation and use of new systems in JERICO-RI. Part 1: HF-radar systems and Deliverable 2.4. Version 1.0. ,DOI: http://dx.doi.org/10.25607/OBP-1005D2.4 [Horstmann and del Rio, J. et al 2019]	*2*	*One of the main references for the whole HF Radar section of the present e-handbook*
Report on first methodological improvements on retrieval algorithms and HF radar network design., Deliverable D3.3, Version 1.I.DOI: http://dx.doi.org/10.25607/OBP-947 [Corgnati,, et al 2017]	*9*	*Relevant for the current section: Chapter 3.3 recommendations for Integrated HF radar network design at regional scale*

6.4. Sensors and integration into platform

6.4.1. General description

HFR sensors are remote sensing instruments based on the principle of Bragg scattering of the electromagnetic radiation over the rough conductive sea surface [Crombie, 1955]. They infer the radial current component from the Doppler shift of radio waves backscattered by surface gravity waves of half their electromagnetic wavelength. Each single radar site is configured to estimate radial currents moving toward or away from the receive antenna.

The speed of the wave is derived from linear wave theory and then the velocity of the underlying ocean surface currents is retrieved by subtraction. The distance to the backscattered signal is determined by range-gating the returns. Depending on the hardware settings and the methodology used to determine the incoming direction of the scattered signal, commercial HFR systems can be differentiated into two major types: Beam Forming (BF) and Direction Finding (DF). BF radars use linear phased arrays of receive antennas (8 to 16 antennas in a linear array) to electronically steer the sensing beam [Gurgel, et al, 1999]. DF radars [Barrick, et al., 1985] measure the return signal continuously over all angles, exploiting the directional properties of a three-element antenna system (two directionally dependent orthogonal crossed loops and a single omnidirectional monopole) and use the Multiple Signal Characterization (MUSIC) DF algorithm [Schmidt, 1986] for determining the direction of the incoming signals.

HFR systems operate at specific frequencies within the 3–50-MHz band and provide radial measurements which are representative of current velocities in the upper 0.5–2 metres of the water column, depending on the central frequency [Stewart and Joy, 1974]. In regions of overlapping coverage from two or more sites, radial current estimations are geometrically combined to estimate total current vectors on a predefined Cartesian regular grid.

The specific geometry of the HFR domain and the intersection angles of radial vectors influence the accuracy of the total current vectors resolved at each grid point, which is quantified via a dimensionless parameter named Geometrical Dilution of Precision (GDOP) [Chapman, 1997].

6.4.2. Detailed description

Around 400 HF Radar stations are operational worldwide [Roarty et al., 2019], however reported numbers in international data portals may vary widely, depending on the level of HFR stations integration in regional networks and the availability of near real time data.

From a recent survey of EuroGOOS HFR Task Team [Mader, et al, 2017] it appears that the main commercial HF Radar models identified are SeaSonde (from CODAR Ocean Sensors, US) [Barrick, et al, 1977] and WERA (from HELZEL Messtechnik, Germany [Gurgel, et al, 1999; Helzel, et al, 2007] while a third model, called LERA and operational as first prototype from 2013 at The University of Hawaii [Flament, et al, 2016], is not mentioned. The same result is obtained browsing the OceanOPS interactive board (https://www.ocean-ops.org/board): out of 270 HFR platforms worldwide, only the two Codar and WERA above-mentioned models are listed as operational. Therefore, the recommendations provided here mostly refer to those models.

Overview and detailed description can be found respectively at https://codar.com/seasonde/ and https://helzel.com/product-detail-wera/.

It is worth mentioning that they represent the two groups in which HF radars are commonly classified with respect to the method used for resolving the sea echo direction of arrival (DOA) in azimuth: SeaSonde for direction finding and WERA for beamforming.

HFR sensors typically consist of receiving and transmitting rack-mountable units that are located indoor in an air conditioned environment, and a set of outdoor antennas whose dimension, number and arrangement is variable.

The official frequency bands in which HF oceanographic radars can operate are defined by the International Telecommunication Union (ITU) Resolution 612, 2012. [ITU, 2014]. The transmitting unit sends a radio signal modulated in frequency in a range of hundreds of kHz depending on the national regulations (i.e. available/allowed bandwidth). The receiving unit samples the signal backscattered by the ocean surface and sends it to the computer for further processing steps. One or more computers control the receiving and transmitting units and run the processing software, and a surface current map is produced typically every hour.

Table 6-2: HF radar optimum range performance for surface current measurements with respect to the operating frequency for radio bands allocated in Europe (Region 1) for oceanographic radars. Range depends also on water salinity. Range resolution is also provided vs available bandwidth. For wave retrieval the optimum range reduces by approximately 30%.

	ITU Frequency	**Optimum Range SeaSonde**	**Optimum Range WERA**	**Bandwidth**	**Range Resolution**	**Bragg Wavelength**

	[kHz]	[km]	[km]	[kHz]	[km]	[m]
Long Range	4438	220	500	25	6	34
	4488					
	5250	175	400	25	6	28
	5275					
Medium Range	9305	80	200	50	3	16
	9355					
	13450	60	110	100	1,5	11
	13550					
	16100	60	90	100	1,5	9
	16200					
Short Range	24450	30	60	150	1	6
	24600					
	26200	30	55	150	1	6
	26350					
	39000	20	30	250	0.6	4
	39500					
	42000	15	25	325	0.46	4
	42500					

6.4.3. Sensor calibration

The analysis of the radar signals to resolve the azimuth needs a good knowledge of the receiving antenna specificities. Any HFR system is subject to the influence of the nearby environment, and should be always calibrated once in place [Kohut and Glenn, 2003; Yang et al, 2018], as an important part of the system setup and maintenance, in order to verify the theoretical antenna response and to introduce correction factors if needed. Calibration can be performed with different techniques, among which two are the most common: internal calibration method, commonly applied to BF systems, and far-field calibration method, also known within the HFR community as antenna pattern measurement (APM), usually applied to DF configurations.
Further details can be found in [Mantovani et al, 2020] in chapter "Receiving Antenna Calibration" and references herein.

6.4.4. Uncertainties in observations

A number of papers identify sources of uncertainty in HFR surface current data.
One source of uncertainty arises from pure geometry in the process of combining radial velocities into total velocity vectors and is described in (Chapman et al., 1997; Barrick, 2006).
In [Lipa, 2013], we can identify different sources of uncertainty in the radial velocities:

- Variations of the radial current component within the radar scattering patch
- Variations of the current velocity field over the duration of the radar measurement
- Errors/simplifications in the analysis (e.g. incorrect antenna patterns or errors in empirical first order line determination, [Emery and Washburn, 2019; Kirincich, 2017].

Statistical noise in the radar spectral data, which can originate from power-line disturbances, radio frequency interferences, ionosphere clutter, ship echoes, or other environmental noise [Kohut and Glenn, 2003]

Related to the data uncertainties, it is worth mentioning that a number of validation exercises exist, based on comparisons of HFR currents against independent in situ measurements [Chapman et al, 1997; Kohut and Glenn, 2003; Kaplan et al, 2005; Paduan et al, 2006; Ohlmann, et al, 2007; Cosoli et al, 2010; Solabarrieta et al., 2014; Lorente et al, 2014, 2015a, 2015b; Kalampokis, et al., 2016]. These validation exercises can be limited by the fact that part of the discrepancies observed through these comparisons are due to the specificities and own inaccuracies of the different measuring systems.

6.4.5. Quality Assurance methods

First Quality Assurance is achieved when recommendations are satisfied for the HFR site selection and for the required accessories described in 6.3.1. "Design and functionality of platform" of the present manual.
Other important methods for ensuring the optimal condition for data acquisition are:

- Antennas should be installed in such a way that their stability is ensured in all weather conditions
- Antennas should be tuned for the intended operating frequency
- Antennas should be calibrated
- Regular maintenance should be carried on
- Diagnostic reporting should be received and analyzed regularly

Details on the above recommendations can be found in (Mantovani et al., 2020) in section Setup and Maintenance, and references cited herein.
Finally, Quality Control on data is well developed and harmonized at European level and is explained in the following section 6.5.3 "Quality Control and Quality Assurance"

An example of the use of non-velocity-based metrics related to the characteristics of the received signal (radial and total coverage analysis, hardware status, quality of the received] signal) to implement advanced quality controls is provided in [Kirincich et al, 2012]. Other advanced methods are suggested in literature, none of them is systematically defined and used in JERICO RI community yet.

6.4.6. Issues

A number of factors affect HFR performances during setup and operation with impact on data accuracy or with an interruption of data flow. Environmental factors, such as low sea state or extreme wave conditions, can introduce spatial and temporal data gaps due either to the low-energy environment or the saturation of the spectrum region delimiting the first order Bragg peaks (1st order region); radio interference may contaminate the 1st order region and bias the radial current maps.

HF radars give a unique view of ocean currents, however they are limited to the surface.

Radio interference is a main issue affecting HF Radars. Despite the fact that frequency band allocation is regulated by The International Telecommunication Union, anthropogenic electromagnetic noise often saturates in an unpredictable way the frequency spectrum generating spatio-temporal gaps in the surface velocity maps.
Finally, the complexity of algorithms behind the estimation of the ocean variables makes it difficult to identify the direct effect of improper settings or hardware malfunctions.

6.4.7. HF Radar Sensor best practices and standards

- Contributing Best Practices

Table 6-3: HF Radar - Sensor best practices

Best Practice /title	refer in Annex I	Notes
Report on Best Practice in the implementation and use of new systems in JERICO-RI. Part 1: HF-radar systems and Deliverable 2.4. Version 1.0. ,DOI: http://dx.doi.org/10.25607/OBP-1005D2.4 [Horstmann and del Rio, et al, 2019]	*2*	*One of the main references for the whole HF Radar section of the present e-handbook*
Report on first methodological improvements on retrieval algorithms and HF radar network design, Deliverable D3.3. Version 1. [Corgnati, et al, 2017]	*9*	
Report on final assessment of methodological improvements and testing on infrastructures, Version 2 [Griffa, et al (20219]	*10*	

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- Standards

The international harmonised standards used for design, testing, performance and in the regulatory framework are the following:

Table 6-4: HF Radar - Standards

Standard	Description
Global Positioning System (GPS) Standard Positioning Service (SPS)	SPS is used in most of the commercial models for synchronizing multiple HFR stations operating at the same frequency, so that interferences are avoided between radar of the same type.
Radio Frequency (RF) - 50 Ohm impedance - standard coaxial connectors and cables	A variety of 50 Ohm standard coaxial connectors and cables are used for connecting receiving and transmitting units with the external RF antennas and lighting protection modules.
The Radio Equipment Directive (RED, EU directive 2014/53/EU)	All the radio equipment placed on the European Union market must adhere to this directive. HF radars are included, but also for instance WiFi routers. RED "...ensures a single market for radio equipment by setting essential requirements for safety and health, electromagnetic compatibility, and the efficient use of the radio spectrum…" (https://ec.europa.eu/growth/sectors/electrical-and-electronic-engineering-industries-eei/radio-equipment-directive-red_en)
International Telecommunication Union (ITU) Resolution 612, 2012	It regulates the use of the radiolocation service between 3 and 50 MHz to support oceanographic radar operations

6.5. Data and data management methods

6.5.1. Description of data

This section briefly describes the types of data to be managed. The main geophysical variable measured by High Frequency Radars (HFR) is the near-surface sea water current velocity. Data generated from HFR measurements are two-dimensional gridded data and they are of two types: radial data and total data. The term 'radial' refers to current velocities lying on radial lines centred in each of the measurement sites. The term 'total' refers to the effective near-surface current velocity, which is obtained from the combination of the radial data from at least two radar sites. Radial velocity vectors can be considered the radial components of the total velocity vectors.

Depending on the instrument manufacturer and on the acquisition method, raw data acquired by HFR systems present different variable sets and different names for common variables. Anyway, the geophysical content of data from all HFR systems can be considered to be the same.

Radial data contain magnitude and direction of near-surface seawater radial current velocities, near-surface zonal and meridional components of sea water radial current velocities, standard deviation of near-surface zonal and meridional components of sea water radial current velocities, quality flags and metadata. Figure 1 shows an example of radial velocity data measured by HFR systems.

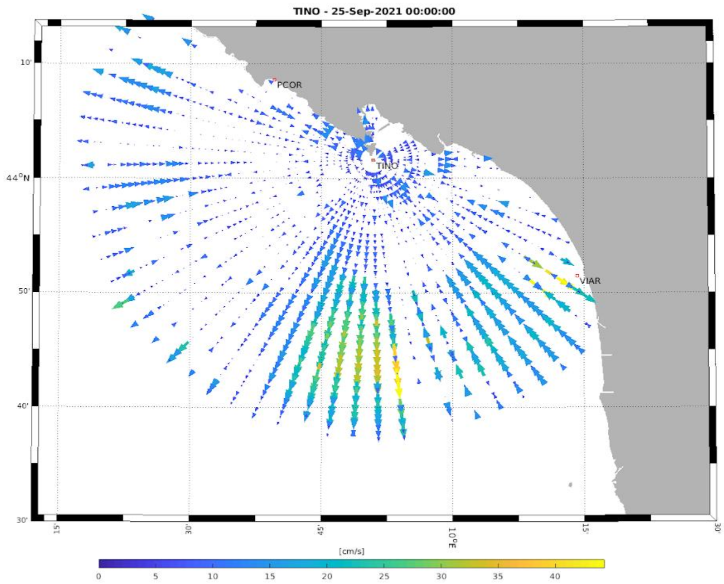

Figure 6-4: Radial velocity field measured by the TINO HFR station (located at Isola del Tino, in the Ligurian Sea), belonging to the HFR-TirLig network.

Total data contain near-surface zonal and meridional components of sea water current velocities, standard deviation of near-surface zonal and meridional components of sea water current velocities, Geometrical Dilution of Precision (GDOP) [Chapman, et al, 1997; Kim, et al, 2007], quality flags and metadata. Figure 6-5 shows an example of total velocity data measured by HFR systems.

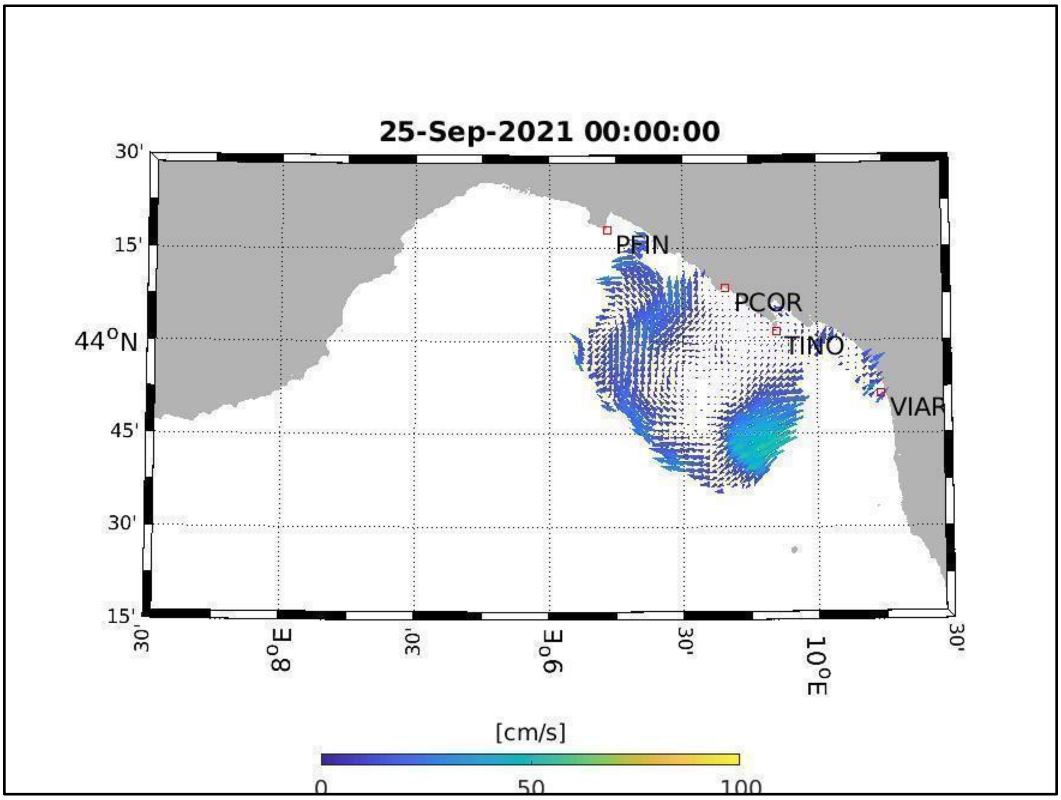

Figure 6-5: Total velocity field measured by the HFR-TirLig network in the Ligurian Sea.

In addition to surface coastal ocean currents, HFR measures directional wave spectrum and derived parameters (i.e. significant wave height, wave period, mean wave direction) as well as wind intensity and direction, but these data types are out of the scope of the present document, since standardization is not yet existing. Thus, from now on, only HFR radial and total sea water current velocities will be considered in this document.

6.5.2. Data value chain: from acquisition to delivery

- Methodologies used for data collection

High Frequency Radars are land-based systems for remote sensing of ocean surface currents and waves, thus a continuous access to their measurements is possible via different communication technologies. This allows the establishment of Near Real Time dataflows. Depending on the HFR manufacturer and operational configurations, the native data formats may be different, as well as the variable names and the metadata. In order to foster the coordinated development of HFR technology and its products for ensuring the full exploitation of its potential within the development of the European operational oceanography, a common European QC, data and metadata model has been defined [Corgnati et al, 2018] and operational tools and services have been developed to automatically ingest and harmonize data coming from different HFR data sources.

In this framework, the European High Frequency Radar Node (EU HFR Node) was established in 2018 by AZTI, CNR-ISMAR and SOCIB, under the coordination of the EuroGOOS HFR Task Team (http://eurogoos.eu/high-frequency-radar-task-team/), as the focal point and operational asset in Europe for HFR data management and dissemination, also promoting networking between EU infrastructures and the Global HFR network. The EU HFR Node is fully operational since December 2018 in distributing tools and support for standardization to the HFR providers. At present, the EU HFR Node manages data from 16 European HFR networks (built by 53 radar sites) and integrates US HFR network data (173 radial stations, grouped in 5 networks). In particular, the EU HFR Node implements the following functions:

- data acquisition and harvesting
- quality control (QC)
- conversion to the European standard data format for HFR current data
- validation/assessment
- delivery of NRT and historical HFR current data with different reprocessing levels.

The EU HFR Node service is founded on a simple and very effective rule: if the data provider can set up the data flow according to the defined standards, the node only collects, checks and distributes the datasets. If the data centre cannot set up the data flow, the EU HFR Node directly harvests the raw data from the provider, harmonizes, quality-controls and formats these data and makes them available to the marine portals. The strength and flexibility of this solution reside in the architecture of the European HFR node, which is based on a centralized database, fed and updated by the operators via a webform (webform.hfrnode.eu). The database contains updated metadata of the HFR networks and the needed information for processing/archiving the data.

The collection of HFR data is operated either in real time directly from the radial stations (for providers relying on the node processing service) or from the storage systems (for providers sending standardized data) via rsync protocol. The data are synchronized towards the EU HFR Node servers, where they are processed and/or validated.

The guidelines on how to set the data flow from HFR providers to the EU HFR Node are described in [Reyes, et al, 2019].

Figure 6-6 shows the possible dataflows implemented by the EU HFR Node for data harmonization and distribution.

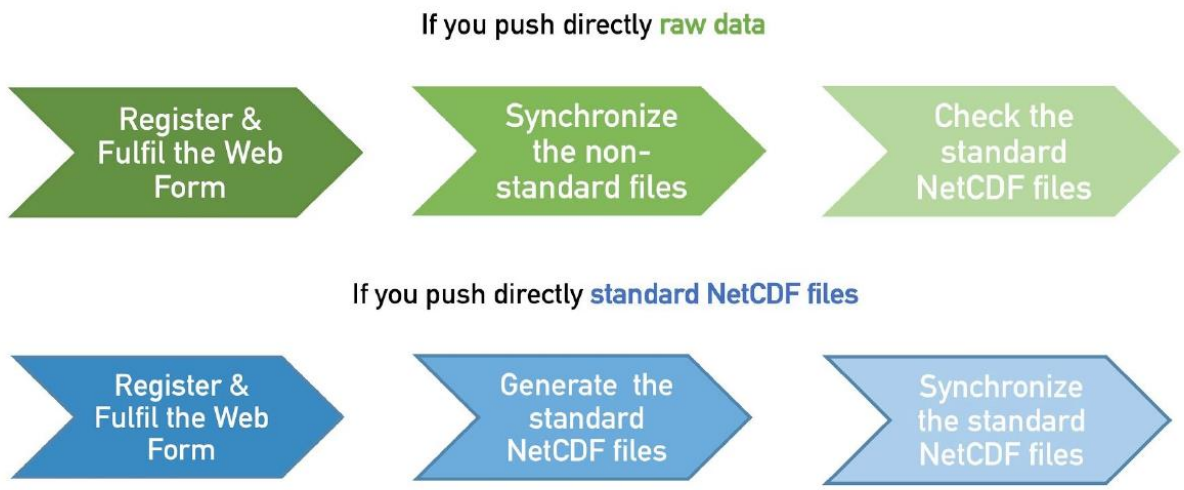

Figure 6-6: Workflow for the integration of HFR data in the EU HFR node (picture from (Reyes et al., 2019)

- Metadata information and data format

This section details the standards applied to data and metadata format and syntax using community agreed vocabularies. The EU HFR Node generates datasets of HFR-derived current measurements compliant to the European common QC, data and metadata model for real-time HFR current data (Corgnati, et al, 2018], that is the official European standard for HFR real-time current data, allowing to ensure efficient and automated HFR data discovery and interoperability with tools and services across distributed and heterogeneous earth science data systems.

The model was implemented according to the standards of Open Geospatial Consortium (OGC) for access and delivery of geospatial data, and compliant with the Climate and Forecast Metadata Convention CF-1.6, the Copernicus Marine Environment Monitoring Service In Situ Thematic Assembly Center (CMEMS-INSTAC) conventions, the Unidata NetCDF Attribute Convention for Data Discovery (ACDD), the OceanSITES convention and the INSPIRE directive. The model also follows the guidelines of the Data Management, Exchange and Quality Working Group (DATAMEQ) and fulfils the recommendations given by the Radiowave Operators Working Group (US ROWG).

The European common QC, data and metadata model for real-time HFR current data integrates the SeaDataCloud (SDC) requirements about the SeaDataNet metadata services (https://www.seadatanet.org/Metadata) for enforcing discovery and access of HFR data and in order to gain visibility and valorization for the projects and the institutions producing HFR data.

The HFR related metadata directories constituting the SeaDataNet metadata services are:

- European Directory of Marine Organisations (**EDMO**): it contains up-to-date addresses and activity profiles of research institutes, data holding centres, monitoring agencies, governmental and private organisations, that are in one way or another engaged in oceanographic and marine research activities, data and information management and/or data acquisition activities (https://www.seadatanet.org/Metadata/EDMO-Organisations).

- European Directory of the Initial Ocean-Observing Systems (**EDIOS**): it gives an overview of the ocean measuring and monitoring systems operated by European countries. This directory includes discovery information on location, measured parameters, data availability, responsible institutes and links to data-holding agencies plus some more technical information on instruments (https://www.seadatanet.org/Metadata/EDIOS-Observing-systems).
- Common Data Index (**CDI**): it gives users a highly detailed insight in the availability and geographical spreading of marine data sets and it provides a unique interface for requesting access, and if granted, for downloading datasets from the distributed data centres across Europe (https://www.seadatanet.org/Metadata/CDI-Common-Data-Index).

EDMO, EDIOS and CDI entries are xml files to be prepared using Mikado software (https://www.seadatanet.org/Software/MIKADO). Entries have to be mailed to sdn-userdesk@seadatanet.org for ingestion.

Each HFR data provider is mandatorily asked to have EDMO, EDIOS and CDI entries.

SDC is also managing the following catalogs:

- European Directory of Marine Environmental Research Projects (**EDMERP**): it covers marine research projects for a wide range of disciplines. Research projects are described as metadata factsheets with their most relevant aspects. The primary objective is to support users in identifying interesting research activities and in connecting them to involved research managers and organizations across Europe (https://www.seadatanet.org/Metadata/EDMERP-Projects).

- European Directory of Marine Environmental Datasets (**EDMED**): it is a comprehensive reference to the marine data sets and collections held within European research laboratories, so as to provide marine scientists, engineers and policy makers with a simple mechanism for their identification. It covers a wide range of disciplines (https://www.seadatanet.org/Metadata/EDMED-Datasets).

EDMERP and EDMED entries are xml files to be prepared using Mikado software (https://www.seadatanet.org/Software/MIKADO). Entries have to be mailed to sdn-userdesk@seadatanet.org for ingestion.

HFR data providers are invited to provide EDMERP and EDMED entries.

The European common QC, data and metadata model for real-time HFR data uses **NetCDF** (Network Common Data Form), a set of software libraries and machine-independent data formats that is an international standard for sharing scientific data.

The recommended implementation of NetCDF is based on the community-supported Climate and Forecast Metadata Convention (CF), which provides a definitive description of the data in each variable, and the spatial and temporal properties of the data. The used version is **CF-1.6** and it must be identified in the *Conventions* attribute.

The European common data and metadata model for real-time HFR data adds some requirements to the CF-1.6 standard, to fulfil the requirements of CMEMS-INSTAC and SDC CF extension.

In particular:

- where time is specified as a string, the **ISO8601 standard "YYYY-MM-DDThh:mm:ssZ"** is used; this applies to attributes and to the base date in the *units* attribute for time. There is no default time zone; **UTC** must be used, and specified.
- Global attributes from **Unidata's NetCDF Attribute Convention for Data Discovery (ACDD)** are implemented.
- **INSPIRE directive compliance** is recommended.
- Variable names from **SeaDataNet (SDN) P09 controlled vocabulary** are used.

The QC, data and metadata model applies to both real-time radial velocity data and real-time total velocity data.

The European Common format for HFR real-time data is **NetCDF-4 classic model format.**

NetCDF-4 is the state of the art version of the NetCDF library and it has been launched in 2008 to support per-variable compression, multiple unlimited dimensions, more complex data types, and better performance, by layering an enhanced NetCDF access interface on top of the HDF5 format.

At the same time, a format variant, NetCDF-4 classic model format, was added for users who needed the performance benefits of the new format (such as compression) while keeping backward compatibility with previous versions.

The components (dimensions, variables and attributes) of NetCDF data set are described in the following.

The **global attribute** section of a NetCDF file describes the contents of the file overall, and allows for data discovery. All fields should be human-readable and use units that are easy to understand. Global attribute names are case sensitive.

The European common QC, data and metadata model for real-time HFR data divides global attributes to be adopted for HFR data in three categories: Mandatory Attributes, Recommended Attributes and Suggested Attributes.

The Mandatory Attributes include attributes necessary to comply with CF-1.6, OceanSITES and CMEMS-INSTAC conventions (Copernicus-InSituTAC-FormatManual-1.41. Copernicus-InSituTAC-SRD-1.5, Copernicus-InSituTAC-ParametersList-3.2.0). The global attributes required for the SDC Common Data Index (CDI) scheme and the SDC CF extension are mandatory as well.

The Recommended Attributes include attributes necessary to comply with INSPIRE and Unidata Dataset Discovery conventions.

The Suggested Attributes include attributes that can be relevant in describing the data, whether it is part of the standard or not.

Attributes are organized by function: Discovery and Identification, Geo-spatial-temporal, Conventions used, Publication information and Provenance.

The complete list of global attributes, their description and the required syntax are reported in Section 5.2 of [(Corgnati, et al., 2018]. available in the Ocean Best Practices Repository at http://dx.doi.org/10.25607/OBP-944

NetCDF **dimensions** provide information on the size of the data variables, and additionally tie coordinate variables to data. CF recommends that if any or all of the dimensions of a variable have the interpretations of "date or time" (T), "height or depth" (Z), "latitude" (Y), or "longitude" (X) then those dimensions should appear in the relative order T, Z, Y, X in the variable's definition.

In the specific case of HFR radial data files, if the radial measurements are taken by the instruments based on a polar geometry (e.g. Codar .ruv files), the X and Y axis dimension shall be "bearing" (Y) and "range" (X). In this case, anyway, latitude and longitude shall be present in the NetCDF file as data variable.

Since HFR data have only one depth layer of measurement, i.e. the surface layer, the depth dimension must have size equal to 1 and value equal to 0 metres.

If non-physical variables are present in the data file, e.g. the processing parameters of the HFR device generating the data or the codes of the sites contributing to a total velocity data, related non-physical dimensions may be defined to expose the variables in the model.

The complete list of dimensions, their description and the required syntax are reported in Section 5.3 of [Corgnati, et al, 2018].

NetCDF **coordinates** are a special subset of variables. **Coordinate variables** orient the data in time and space; they may be dimension variables or auxiliary coordinate variables (identified by the *coordinates* attribute on a data variable).

Coordinate variables have an *axis* attribute defining that they represent the X, Y, Z, or T axis. The only exception is the crs variable, that is an ancillary coordinate variable required by the SDC CF extension.

Missing values are not allowed in coordinate variables.

The latitude and longitude datum is **WGS84**, i.e. the default output of GPS systems.

Bearing and range are the coordinate variables for radial velocity data. For radial data measured on a polar geometry (e.g. Codar .ruv files), latitude and longitude are data variables since they are evaluated starting from bearing and range.

The complete list of coordinate variables, their description and the required syntax are reported in Section 5.4 of [Corgnati et al, 2018], available in the Ocean Best Practices Repository at http://dx.doi.org/10.25607/OBP-944

The SDN extensions to CF were concerned with providing storage for standardized semantics and metadata included in the SDN profiles format. In addition to extending coordinate variables and attributes within variables, there are a number of **SDN namespace variables** that form part of the SeaDataCloud extension.

The complete list of SDN namespace variables, their description and the required syntax are reported in Section 5.5 of [Corgnati et al, 2018], available in the Ocean Best Practices Repository at http://dx.doi.org/10.25607/OBP-944

Data variables contain the actual measurements and information about their quality, uncertainty, and mode by which they were obtained.

The European common QC, data and metadata model for real-time HFR data divides data variables to be adopted for HFR data in two categories: Mandatory Variables and Recommended Variables.

When an appropriate CF standard name is available, it is required to be used; if no such name exists in the CF standard, the *standard_name* attribute should not be used. In those cases, the *long_name* attribute has to be used. Please refer to the CF Standard Names table online for authoritative information (definitions, canonical units) on standard names.

It is recommended that variable names be a 4-character-capitalized-letters name. They are not strictly standardized, however; one should use the CF *standard_name* attribute to query data files. Note that a single standard name may be used more than once in a file, but variable names are unique.

Data variables required in the SDC CF extension are mandatory as well.

Each data variable is equipped with specific attributes, named **variable attributes.** Variable attributes can be mandatory or recommended, however the European QC, data and metadata model for real-time HFR data recommends that all other attributes be used and contain meaningful information, unless technical reasons make this impossible. Variable attributes required in the SDC CF extension are mandatory.

Even if CF conventions prefer the use of coordinate variables as dimensions, because it conforms to COARDS (Cooperative Ocean-Atmosphere Research Data Service) convention and because it simplifies the use of the data by standard software, in order to comply with

SDC CF extension data model, the European common QC, data and metadata model for NRT HFR data mandates to declare the variables with all their dimensions and also to have the *coordinates* attribute filled with the list of dimensions.

The complete list of data variables and related attributes, their description and the required syntax are reported in Section 5.6 of [Corgnati et al., 2018], available in the Ocean Best Practices System Repository at http://dx.doi.org/10.25607/OBP-944

- Data policy

A common and standardized data policy for HFR data does not exist: the access to HFR data is regulated by each data provider. Anyway, the EU HFR Node recommends the free distribution of HFR data by the adoption of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/).

At present, data from 15 out of the 16 European HFR networks and from the whole US network (i.e. data from 223 out of the 226 HFR radial sites, counting for 98.7% of the managed radial sites) are freely distributed using the Creative Commons Attribution 4.0 International License. These data are accessible for discovery and download via the EU HFR Node THREDDS catalogue at thredds.hfrnode.eu

- Data dissemination – Link to European/International Data Banks

Since December 2018 the EU HFR Node operationally distributes standardized Near Real Time HFR derived current data (both radial and total velocity data) from European and US networks towards CMEMS-INSTAC (http://www.marineinsitu.eu/) and EMODnet Physics (https://portal.emodnet-physics.eu/) marine data portals.

NRT HFR current data are available and freely accessible in the following CMEMS-INSTAC data products:

- INSITU_GLO_PHY_UV_DISCRETE_NRT_013_048
- INSITU_GLO_PHYBGCWAV_DISCRETE_MYNRT_013_030
- INSITU_ARC_PHYBGCWAV_DISCRETE_MYNRT_013_031
- INSITU_BAL_PHYBGCWAV_DISCRETE_MYNRT_013_032
- INSITU_IBI_PHYBGCWAV_DISCRETE_MYNRT_013_033
- INSITU_MED_PHYBGCWAV_DISCRETE_MYNRT_013_035
- INSITU_NWS_PHYBGCWAV_DISCRETE_MYNRT_013_036

NRT HFR data are available and freely accessible within the EMODnet Physics data portal by applying the filter 'Radar' in the 'Platform Type' menu.
The EU HFR Node operationally distributes standardized Delayed Mode HFR derived current data (both radial and total velocity data) from European and US networks towards CMEMS-INSTAC (http://www.marineinsitu.eu/) and SDC Data Access (https://www.seadatanet.org) marine data portals.

Delayed Mode HFR current data are available and freely accessible in the following CMEMS-INSTAC data products:

- INSITU_GLO_PHY_UV_DISCRETE_MY_013_044

Delayed Mode HFR current data are freely accessible within SDC Data Access portal by using the 'HFR' keyword in the search field of the CDI discovery page at https://cdi.seadatanet.org/search.

- Examples of HFR Data Management Plan

The examples of data management plans (DMPs) reported in Table 9 are from diverse HFR providers. The plans are integrated documents that describe how the data and operations are handled, also providing an overview of the responsibilities and roles from the different actors involved through the value chain.

Table 6-5: Data Management Plans for HFR data.

HFR Data Management Plan	Link/DOI
SOCIB - Coastal High Frequency Radar Data Management Plan (Version 1.0) (Marasco et al., 2021)	https://doi.org/10.25704/ydas-qz53
NANOOS - Northwest Association of Networked Ocean Observing Systems	http://www.nanoos.org/documents/certification/DMP/1.DMP.HFRadar.pdf
IMOS - Integrated Marine Observing System	https://s3-ap-southeast-2.amazonaws.com/content.aodn.org.au/Documents/IMOS/Workflows/OceanRadar_CODAR_Workflow.pdf
Harlan, J., Terrill, E., & Crout, R. (2008). NOAA IOOS national HF radar network data management: Status and Plans. *2008 IEEE/OES 9th Working Conference on Current Measurement Technology*, 156–159.	https://doi.org/10.1109/CCM.2008.4480860

6.5.3. Quality Control and Quality Assurance

Quality Control variables are variables storing the results of specific Quality Control (QC) tests to be applied to data, as mandated by the European common QC, data and metadata model for NRT HFR data (see Table 6-8 and Table 6-9).

Since in HFR data the quality control values vary along one or more axes of the data variables, they are provided as separate numeric flag variables, with at least one dimension that matches the 'target' variable.

When QC information is provided as a separate flag variable, CF-1.6 requires that these variables carry the *flag_values* and *flag_meanings* attributes. These provide a list of possible values and their meanings.

QC variables can also exist not linked to a target physical variable (e.g. GDOP threshold QC variable linked to GDOP variable), but also as standalone variables reporting the results of a specific QC test, e.g. Over-water test (see Section 3.1.4).

No CF-1.6 standard names exist for QC variables, thus long names have to be used. QC variables must be of type short.

Each QC variable is equipped with specific variable attributes, which can be mandatory or recommended. However the European QC, data and metadata model for real-time HFR data recommends that all other attributes be used and contain meaningful information, unless technical reasons make this impossible.

The complete list of QC variables and related attributes, their description and the required syntax are reported in Section 5.7 of [Corgnati, et al, 2018], available in the Ocean Best Practices System Repository at http://dx.doi.org/10.25607/OBP-944

The European QC, data and metadata model for real-time HFR data strongly recommends the application of **data packing**, i.e. a method for reducing the data volume by reducing the precision of the stored numbers. It is implemented using the variable attributes *add_offset* and *scale_factor*. After the data values of a variable have been read, they are to be multiplied by the *scale_factor* and have *add_offset* added to them. If both attributes are present, the data are scaled before the offset is added. When scaled data are written, the application should first subtract the offset and then divide by the scale factor. The units of a variable should be representative of the unpacked data. If the *scale_factor* and *add_offset* attributes are of the same data type as the associated variable, the unpacked data is assumed to be of the same data type as the packed data. However, if the *scale_factor* and *add_offset* attributes are of a different data type from the variable (containing the packed data) then the unpacked data should match the type of these attributes, which must both be of type float or both be of type double. An additional restriction in this case is that the variable containing the packed data must be of type byte, short or int. It is not advised to unpack an int into a float as there is a potential precision loss. When data to be packed contains missing values, the attributes that indicate missing values (*_FillValue*, *valid_min* , *valid_max* , *valid_range*) must be of the same data type as the packed data. Please refer to the NetCDF Climate and Forecast Metadata Conventions (https://cfconventions.org/Data/cf-conventions/cf-conventions-1.7/cf-conventions.html) for further details about data packing.

The **data type** is a bigram used in file names for a quick identification of the file content, in the framework of the adopted **naming convention**. According to CMEMS-INSTAC requirements, data filenames must contain the two bigrams '_XX_YY_', where:

- the bigram 'XX' indicates the type of measurement;
- the bigram 'YY' indicates the data type.

For HFR data the two bigrams 'XX' and 'YY' are defined as:

- XX=TV (Total Velocity) for total current data files;
- XX=RV (Radial Velocity) for radial current data files;
- YY=HF

Thus, the two bigrams 'XX_YY' inside the filenames are:

- 'TV_HF' for total current velocity data files;
- 'RV_HF' for radial current velocity data files.

Please refer to CMEMS-INSTAC System Requirement Document (http://archimer.ifremer.fr/doc/00297/40846/50211.pdf) for further details about the adopted naming convention.

In order to fulfil the specific requirements of CMEMS-INSTAC, EMODnet Physics and SDC Data Access, that are operationally distributing NRT and historical HFR data since 2019, the European common QC, data and metadata model for NRT HFR data was declined for those specific applications: the manual for the standard QC, data and metadata model adopted in CMEMS-INSTAC and EMODnet Physics is described in [Copernicus Marine In Situ Tac Data Management Team, 2020], the one for SDC Data Access is described in [Corgnati et al, 2019].

The following table reports the links to the documents that build the QC, data and metadata standard model for NRT HFR current data.

Table 6-6: Links to the documents that build the QC, data and metadata standard model for NRT HFR current data.

Manual	Link
European common QC, data and metadata model	https://repository.oceanbestpractices.org/handle/11329/1441
CMEMS-INSTAC Product User Manual	https://archimer.ifremer.fr/doc/00620/73192/
CMEMS-INSTAC Quality Information Document	https://archimer.ifremer.fr/doc/00301/41256/
CMEMS-INSTAC NetCDF format manual	https://archimer.ifremer.fr/doc/00488/59938/
SeaDataNet HFR model	https://repository.oceanbestpractices.org/handle/11329/1511

- Near-Real Time QC

The European common QC, data and metadata model for NRT HFR current data [Corgnati et al., 2018] requires both NRT radial and total data to be mandatorily processed by a battery of specific Quality Control (QC) tests. These tests were selected (and modified when needed) by the dedicated working group (composed by the HFR operators and by the EuroGOOS HFR Task Team members) among the ones defined in the IOOS QARTOD Manual for Real-Time Quality Control of High Frequency Radar Surface Current Data [U.S. Integrated Ocean Observing System, 2022], according to the defined hierarchy.

These mandatory QC tests are manufacturer-independent, i.e. they do not rely on particular variables or information provided only by a specific device.

These standard sets of tests were defined both for radial and total velocity data and they are the required ones for labelling the data as Level 2B (for radial velocity) and Level 3B (for total velocity) data. Table 6-4 reports the processing level definitions.

Table 6-7: Processing Levels for HFR data.

Processing Level	Definition	Products
LEVEL 0	Reconstructed, unprocessed instrument/payload data at full resolution; any and all communications artifacts, e.g. synchronization frames, communications headers, duplicate data removed.	Signal received by the antenna before the processing stage. (No access to these data in Codar systems)
LEVEL 1A	Reconstructed, unprocessed instrument data at full resolution, time-referenced and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing.	Spectra by antenna channel
LEVEL 1B	Level 1A data that have been processed to sensor units for next processing steps. Not all instruments will have data equivalent to Level 1B.	Spectra by beam direction
LEVEL 2A	Derived geophysical variables at the same resolution and locations as the Level 1 source data.	HFR radial velocity data
LEVEL 2B	Level 2A data that have been processed with a minimum set of QC.	HFR radial velocity data
LEVEL 2C	Level 2A data that have been reprocessed for advanced QC.	Reprocessed HFR radial velocity data
LEVEL 3A	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency	HFR total velocity data
LEVEL 3B	Level 3A data that have been processed with a minimum set of QC.	HFR total velocity data
LEVEL 3C	Level 3A data that have been reprocessed for advanced QC.	Reprocessed HFR total velocity data
LEVEL 4	Model output or results from analyses of lower level data, e.g. variables derived from multiple measurements	Energy density maps, residence times, etc.

The mandatory QC tests for radial velocity data are listed and described in Table 6-5.

Table 6-8:: Mandatory QC tests for HFR radial data.

QC test	Meaning	QC variable type
Syntax	This test will ensure the proper formatting and the existence of all the necessary fields within the radial NetCDF file. This test is performed on the NetCDF files and it assesses the presence and correctness of all data and attribute fields and the correct syntax throughout the file.	N/A, it is a test on the NetCDF file structure, not on data content.
Over-water	This test labels radial vectors that lie on land with a "bad_data" flag and radial vectors that lie on water with a "good_data" flag.	gridded
Velocity Threshold	This test labels radial velocity vectors whose module is bigger than a maximum velocity threshold with a "bad_data" flag and radial vectors whose module is smaller than the threshold with a "good_data" flag.	gridded
Variance Threshold	This test labels radial vectors whose temporal variance is bigger than a maximum threshold with a "bad_data" flag and radial vectors whose temporal variance is smaller than the threshold with a "good_data" flag. The Codar manufacturer suggests not to use variance data for real-time QC, as documented in the fall 2013 CODAR Currents Newsletter. The indication is due to the fact that the CODAR parameter defining the variance is computed at each time step, and therefore considered not statistically solid. Thus, this test is applicable only to Beam Forming (BF) systems. Data files from Direction Finding (DF) systems will apply instead the "Temporal Derivative" test reporting the explanation "Test not applicable to Direction Finding systems. The Temporal Derivative test is applied." in the comment attribute.	gridded
Temporal Derivative	For each radial bin, the current hour velocity vector is compared with the previous and next hour ones. If the differences are bigger than a threshold (specific for each radial bin and evaluated on the basis of the analysis of a one-year-long time series), the present vector is flagged as "bad_data", otherwise it is labelled with a "good_data" flag. Since this method implies a one-hour delay in the data provision, the current hour file should have the related QC flag set to 0 (no QC performed) until it is updated to the proper values when the next hour file is generated.	gridded

Median Filter	For each source vector, the median of all velocities within a radius of <RCLim> and whose vector bearing (angle of arrival at site) is also within an angular distance of <AngLim> degrees from the source vector's bearing is evaluated. If the difference between the vector's velocity and the median velocity is greater than a threshold, then the vector is labelled with a "bad_data" flag, otherwise it is labelled with a "good_data" flag.	gridded
Average Radial Bearing	This test labels the entire datafile with a 'good_data" flag if the average radial bearing of all the vectors contained in the data file lies within a specified margin around the expected value of normal operation. Otherwise, the data file is labeled with a "bad_data" flag. The value of normal operation has to be defined within a time interval when the proper functioning of the device is assessed. The margin has to be set according to site-specific properties. This test is applicable only to DF systems. Data files from BF systems will have this variable filled with "good_data" flags (1) and the explanation "Test not applicable to Beam Forming systems" in the comment attribute.	scalar
Radial Count	Test labelling radial data having a number of velocity vectors bigger than the threshold with a "good_data" flag and radial data having a number of velocity vectors smaller than the threshold with a "bad_data" flag.	scalar

The mandatory QC tests for total velocity data are listed and described in Table 6-6

Table 6-9: Mandatory QC tests for HFR total data.

QC test	**Meaning**	**QC variable type**
Syntax	This test will ensure the proper formatting and the existence of all the necessary fields within the total NetCDF file. This test is performed on the NetCDF files and it assesses the presence and correctness of all data and attribute fields and the correct syntax throughout the file.	N/A, it is a test on the NetCDF file structure, not on data content.
Data Density Threshold	This test labels total velocity vectors with a number of contributing radials bigger than the threshold with a "good_data" flag and total velocity vectors with a number of contributing radials smaller than the threshold with a "bad_data" flag.	gridded
Velocity Threshold	This test labels total velocity vectors whose module is bigger than a maximum velocity threshold with a "bad_data" flag and total vectors whose module is smaller than the threshold with a "good_data" flag.	gridded
Variance Threshold	This test labels total vectors whose temporal variance is bigger than a maximum threshold with a "bad_data" flag and total vectors whose temporal variance is smaller than the threshold with a "good_data" flag. The Codar manufacturer suggests not to use variance data for real-time QC, as documented in the fall 2013 CODAR Currents Newsletter. The indication is due to the fact that the CODAR parameter defining the variance is computed at each time step, and therefore considered not statistically solid. Thus, this test is applicable only to Beam Forming (BF) systems. Data files from Direction Finding (DF) systems will apply instead the "Temporal Derivative" test reporting the explanation "Test not applicable to Direction Finding systems. The Temporal Derivative test is applied." in the comment attribute.	gridded
Temporal Derivative	For each grid cell, the current hour velocity vector is compared with the previous and next ones. If the differences are bigger than a threshold (specific for each grid cell and evaluated on the basis of the analysis of a one-year-long time series), the present vector is flagged as "bad_data", otherwise it is labelled with a "good_data" flag. Since this method implies a one-hour delay in the data provision, the current hour file should have the related QC flag set to 0 (no QC performed) until it is updated to the proper values when the next hour file is generated.	gridded

GDOP Threshold	This test labels total velocity vectors whose GDOP is bigger than a maximum threshold with a "bad_data" flag and the vectors whose GDOP is smaller than the threshold with a "good_data" flag.	gridded

Each QC test results in a flag related to each data vector, which is inserted in the specific test variable. These variables can be matrices with the same dimensions of the target data variable, containing, for each cell, the flag related to the vector lying in that cell, in case the QC test evaluates each cell of the gridded data, or a scalar, in case the QC test assesses an overall property of the data.

An overall QC variable reports the quality flags related to the results of all the QC tests: it is a "good data" flag if and only if all QC tests are passed by the data.

The flagging policy is not to modify the data, but only to label them with flags. Thus, each geophysical variable in the standard output files contains exactly the measured data, and the QC variables containing flags can be used as masks to the geophysical variables for having information about data quality.

The adopted QC flagging scheme is the ARGO QC flag scale (which extends the UNESCO scale), as reported in Table 6-7.

Table 6-10: ARGO Quality Control flag scale.

Code	**Meaning**	**Comment**
0	unknown	No QC was performed
1	good data	All QC tests passed
2	probably good data	These data should be used with caution
3	potentially correctable bad data	These data are not to be used without scientific correction or re-calibration
4	bad data	Data have failed one or more QC tests
5	value changed	Data may be recovered after transmission error
6	value below detection	Data value is below detection limit
7	nominal value	The provided value is not measured but comes from a priori knowledge (instrument design or deployment), e.g. instrument target depth
8	interpolated value	Missing data may be interpolated from neighbouring data in space or time

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

9	missing value	

The flags used for NRT HFR data QC are 0: no QC performed; 1: good data; 4 bad data.

For some of these tests, HFR operators need to select the best thresholds. Since a successful QC effort is highly dependent upon selection of the proper thresholds, this choice is not straightforward, and may require trial and error before final selections are made. These thresholds should not be determined arbitrarily, but based on historical knowledge or statistics derived from historical data.

The threshold values are reported in the *comment* variable attribute of each QC variable. The flagging scheme is reported as well in the *flag_values* and *flag_meanings* variable attributes of each QC variable.

The EU HFR Node produces and distributes NRT HFR current data compliant with the European common QC, data and metadata format fo NRT HFR data, thus all the NRT HFR data files generated by the EU HFR Node are processed with the aforementioned QC tests.

- Delayed Mode QC

Delayed Mode (DM) HFR current data must be mandatorily processed with the NRT QC tests. Furthermore, DM HFR data can be processed with additional Advanced Quality Control (AQC) procedures. Following the HFR Node procedures for the production of DM HFR current data, it is recommended that the Historical HFR data time series are screened by means of yearly plots in order to allow the inspection of human experts for assessing the effective quality of HFR data. The following plots by year and system shall be produced:

- temporal series of the spatial average of the current velocity module, its standard deviation and the total spatial coverage
- temporal series of the QC flags for all the grid nodes with data
- maps of the mean value of QC flags for the target year
- maps of mean velocity module and its standard deviation for the target year
- spatial (x-axis) vs. temporal (y-axis) coverage 80/80 annual metric (this allows to check if the system has reached the goal of providing surface currents over the 80% of the area during 80% of the time)
- maps of the mean velocity field in the area of 80% temporal coverage

Based on the data screening and the analysis of the plots listed above, the HFR Node generates reports on the HFR data time series quality per network/sites, where the performance is analysed year by year and periods for reflagging (expert but subjective analysis) are proposed. Reflagging introduces the use of flags 2: probably good data; 3: potentially correctable bad data, until the data can be corrected or is finally discarded.

In addition, possible changes in the processing of the data (namely in the thresholding strategy) are proposed.

The EU HFR Node produces and distributes DM HFR current data compliant with the European common QC, data and metadata format for HFR data, thus all the DM HFR data files generated by the EU HFR Node are processed with the aforementioned AQC procedures. In particular, the EU HFR Node performs the data screening, produces the plots and the reports. Then the proposition for reflagging/reprocessing is divided in two stages, in close collaboration with the data providers:

- In a first step, the report is sent to the provider for its validation and agreement or feedback on the comments and the reflagging/reprocessing proposed.
- Then, after the provider's feedback, changes in the original data series (reflagging or reprocessing) are performed. A final version of the report is produced.

Reflagging is only performed if the provider validates the reflagging proposition. If no reflagging is performed, the DM data contains the same information of the NRT data.

The DM AQC procedures are described in the CMEMS-INSTAC Quality Information Document [Copernicus Marine In Situ Tac, 2020].

6.5.4. Issues

The main issue in HFR data management is the **lack of a unique standard internationally adopted**. US IOOS HFR network and Australian IMOS HFR network, and, in general, each national HFR network outside Europe, apply their own strategy for QC and data models. In Europe three main QC, data and metadata standards exist, i.e. the European common QC, data and metadata model for NRT HFR data, its declinations for distribution towards CMEMS-INSTAC and SDC Data Access data portals, even if they only slightly differ in minor elements. Anyway, this could generate confusion in the data providers and the data users.

- Under the leadership of OceanOPS, the contribution of the European HFR community is crucial towards the achievement of the metadata standardization and integration across the global ocean observing networks, as one of OceanOPS's five goals.
- Representatives of the European HFR Node have participated in the revisiting of the QARTOD manual [U.S. Integrated Ocean Observing System, 2022], together with the US colleagues. This manual reflects the state-of-the-art QC testing procedures for HF radar surface current observations, including also the case study of the European HFR network.

Another vulnerability in HFR data management is the **absence of a common data policy** for HFR data. This should be achieved with priority, in order to enhance the HFR data stream and foster the use of HFR data in societal and scientific applications.

- Giving due credit to all those contributing in the development of new datasets is imperative to incentivize the data publication. Different options listed in [Tanhua, et al, 2019] are: i) the use of data citation tools, such as DOIs (Digital Object Identifiers) or PID (Persistent Identifiers for Data and/or products) attached to the platform (e.g. WMO number for Argo, etc.); ii) the inclusion of metadata records identifying the data provider; iii) the automation of data citation (e.g. ORCID); iv) the definition of consistent ways to count data usage (e.g. MakeDataCount project).
- In the case of HFR network, different metadata (e.g. EDMO, EDIOS and CDI entries) are included referring to the data provider, as mentioned above. However, the definition of the DOI minting strategy for European HFR data (like the one established

for Argo profilers) seeking the convergence in the granularity level, versioning, metadata scheme, citation tracking method, information to be included in the landing page of the DOI, etc. as well as the selection of a FAIR-aligned open repository and the implementation of tools to automate data citations, are still outstanding issues in the HFR community.

Double data distribution from the data provider in non-standard format and from the main European data portals in standard format can also create confusion to the data users, since they often ask which data should they finally use.

- Although metadata and identifiers may benefit double-distributed data traceability, harmonization of data processing and distribution in standard format should be prioritized in a coordinated way (i.e. adopting the European HFR node as focal point for a common data delivery approach) to avoid duplication and heterogeneity, seeking for interoperability to serve both, the data exchanges between networks and user-friendly tools [Tanhua, et al, 2019].

Slow but continuous progress of the adoption of the standards, since only 40% of the 69 ongoing HFR sites in Europe are synchronized with the European HFR node in near real-time [Rubio, et al, 2021]. As mentioned by [Tanhua, et al, 2019], the implementation of the standards can often be beyond the technical capabilities of many scientific communities and, if not, these time-demanding tasks are usually carried out on a voluntary basis from the data provider, being typically funded by science activities. Fortunately, funding and allocation of costs for data management are now encouraged, being no longer an afterthought.

- Leveraging existing software tools, as those listed in section 6.5.5, together with offering support (i.e. by setting up a helpdesk in the European HFR Node), training and outreach (i.e. by webinars and the development of a website explaining the European HFR node role, the responsibilities, the benefits of a centralised standardisation, the return to the data providers, etc) to the teams, can help HFR community significantly increase their level of data interoperability with a minimum of resources.
- In addition, the direct provision of the data in the accepted standards could be an added-value option on the side of the manufacturers [Tanhua, et al, 2019].

Mainly due to its recent creation in December 2018 [Rubio, et al., 2021], the European HFR node still **lacks a well-founded data management plan** and **regular long-term financial** support.

- The development and the publication of a well-established and standardized European HFR node data management plan, evolving throughout the life cycle of the HFR data would benefit the FAIRness of the data. Furthermore, this DMP will be available for all data providers of the European HFR node to be provided for European projects, when requested.
- Effective coordination of the European HFR network and the further establishment and implementation of a robust and sustained governance structure and framework,

as the one recently proposed by [Rubio et al., 2021]), will contribute to support the human and infrastructure resources required to deliver the HFR long-term strategy.

Finally, a minor vulnerability consists in the **absence of a standard procedure for determining the thresholds** of the QC tests. The definition of such a procedure, based on strong scientific foundations, would greatly enhance the effectiveness of the standardized HFR data management.

- Variability of the ocean circulation and, particularly extreme events, often lead to data anomalies. By using novel methods based on deep learning the short-term trend of ocean observation data can be predicted and the error threshold can be better set.

6.5.5. Training materials

The core of the services provided by the EU HFR Node consists in the continuous development of the data model and the processing standards through discussion with operators, providers, distributors and international experts. Based on this, the EU HFR Node maintains and updates manuals, procedure guidelines and software tools, and pushes them towards the HFR operators, providers and managers via repositories and training workshops.

The documentation and the training material related to the implementation of the workflow for HFR current data standardization is reported in Table 6-11.

Table 6-11: Documentation and the training material related to the implementation of the workflow for HFR current data standardization.

Documentation / Training material	Link
Matlab processing software for generation of standardized HFR data	https://cnrsc-my.sharepoint.com/:f:/g/personal/lorenzo_corgnati_cnr_it/EnOTpz7b8H1Am9RGmlwWx8oBtF8uLWkh1ACy9ho7sM3Mkg?e=DC4HtU
EU HFR Node software solutions	https://cnrsc-my.sharepoint.com/:f:/g/personal/lorenzo_corgnati_cnr_it/EtlyL9_9XRxAtBC2j1o99csBrL-hFekUWn41oZ42F_Vgaw?e=uwM5dw
EU HFR Node software dependencies	https://cnrsc-my.sharepoint.com/:f:/g/personal/lorenzo_corgnati_cnr_it/ErCNy-LX6L9Pv-L25vT8b8QBAxqN5XCI2e1OF7sIKE0MqQ?e=DA8zpI
EU HFR Node webform for insertion of information and metadata related to HFR networks and stations	https://cnrsc-my.sharepoint.com/:f:/g/personal/lorenzo_corgnati_cnr_it/EotpWERJVCRGryPEkjddf7kBmJ0fqXJ1lLMhZyKYEZQgug?e=bG4dTB
SeaDataNet metadata for discovery	https://cnrsc-

	my.sharepoint.com/:f:/g/personal/lorenzo_corgnati_cnr_it/Ev4JXQHI85lEim_SRUrFj7YBZnX50jkLZR-rsPGcPL--_g?e=tnQIkO
Guidelines on how to sync HFR radar data from data providers to the EU HFR Node	doi:10.25704/9XPF-76G7

The software tools for processing native HFR data for QC and converting them to the standard format for distribution are continuously made available to HFR operators via public GitHub repositories and releases with DOI assigned, for guaranteeing the complete traceability of the processing chain. Table 6-12 reports the software tools available for data providers who want to locally perform the HFR data standardization.

Table 6-12: Software tools available for data providers who want to locally perform the HFR data standardization.

Software package	Link / DOI
Matlab package for HFR data standardization to be locally run by data providers	DOI:10.5281/zenodo.2639555
Add-on containing all dependencies needed by the Matlab package for HFR data standardization	https://cnrsc-my.sharepoint.com/:u:/g/personal/lorenzo_corgnati_cnr_it/ETqXtGwvyOpAq2a1a_mtiisBpQgGtwwuaO4mAfJIQprfQA?e=RL6QnK
JRadar Java Tool for an easy conversion of HFR radial and total CODAR files into compliant HFR standard NetCDF files	DOI:10.5281/zenodo.5081995 https://github.com/Fundacion-AZTI/JRadar

The Jupyter Notebooks for HFR data analysis developed in the context of CMEMS training actions and other tools developed for obtaining HFR added-value data (i.e. gap-filled data) are also available, as reported in Table 6-13.

Table 6-13: Software tools available for HFR data analysis.

Software package	Link / DOI
Copernicus Marine In Site Arctic Training	https://mybinder.org/v2/gh/CopernicusMarineInsitu/2020-ARC-TrainingWorkshop/dde7e08a502cc4ef92bd3ee0eda10e1c570cc4f2?filepath=13-05-NearRealTime-product-managing-files-hfradars.ipynb
Video Tutorial -Arctic Ocean – In Situ data: Managing In Situ data from HFR radars	https://www.youtube.com/watch?v=bIqGOa_99QE

DIVAnd FREE TOOL developed by GHER (University of Liège) for the interpolation of HFR data available on github	https://github.com/gher-ulg/DIVAnd_HFRadar.jl
HFR data visualization routines in python	https://www.seanoe.org/data/00697/80874/ https://github.com/CopernicusMarineInsitu/2021-sicomar-summer-school

For any further information, other requests or needs, please contact the EU HFR Node by mailing to euhfrnode@azti.es

6.5.6. HF Radar Data best practices and standards

- Contributing Best Practices

Table 6-14: HF Radar - Data best practices and standards

Best Practice /title	refer in Annex I	Notes
D2.4 Report on Best Practice for new network systems- part 1: HF-radar , WP2, Deliverable 2.4. Version 1.0. [Horstmann, J. and del Rio, J. et al, 2019]	*2*	*Relevant for this section of the manual: chapter 5 "Data management"*
D5.14 Recommendation Report 2 on improved common procedures for HFR QC analysis, JERICO-NEXT WP5- Data Management, Deliverable 5.14, Version 1.0. [Horstmann, J. and del Rio, J. et al, 2019]	*20*	*Definition of the European standard data and QC model for NRT HFR data. It is meant to be manufacturer independent.*
OceanSITES Data Format Reference Manual NetCDF Conventions and Reference Tables. Version 1.4 July 16, 2020. Geneva, Switzerland, OceanSITES, JCOMMOPS, 36pp. DOI: http://dx.doi.org/10.25607/OBP-421.2	*37*	
SeaDataNet data management protocols for HF Radar data. WP9 - Deliverable D9.12. Version 1.6	*33*	
Recommendation Report 2 on improved common procedures for HFR QC analysis. JERICO-NEXT WP5-Data Management, Deliverable 5.14, Version 1.0.	*20*	

- Standards used

The international standards and conventions used for standardized HFR data processing are the following:

- Open Geospatial Consortium (OGC) for access and delivery of geospatial data:

https://www.ogc.org/docs/is

- Climate and Forecast Metadata Convention CF-1.6:
  https://cfconventions.org/cf-conventions/v1.6.0/cf-conventions.html
- Unidata NetCDF Attribute Convention for Data Discovery (ACDD):
  https://www.unidata.ucar.edu/software/NetCDF-java/v4.6/metadata/DataDiscoveryAttConvention.html
- ISO8601 standard date and time format:
  https://www.iso.org/iso-8601-date-and-time-format.html
- OceanSITES:
  http://www.oceansites.org/docs/oceansites_data_format_reference_manual.pdf
- INSPIRE Directive:
  https://inspire.ec.europa.eu/
- SeaDataNet Metadata Formats:
  https://www.seadatanet.org/Standards/Metadata-formats
- SeaDataNet Data Transport Formats:
  https://www.seadatanet.org/Standards/Data-Transport-Formats
- CMEMS-INSTAC System Requirements Document (SRD):
  https://archimer.ifremer.fr/doc/00297/40846/
- Integrated Ocean Observing System (IOOS) Quality Assurance / Quality Control of Real Time Oceanographic Data (QARTOD) Manual for Real-Time Quality Control of High Frequency Radar Surface Current Data:
  https://repository.oceanbestpractices.org/handle/11329/288

The following controlled vocabularies are used as well in the standardized HFR data processing:

- National Environment Research Council (NERC) Vocabulary P01:
  https://vocab.nerc.ac.uk/search_nvs/P01/
- National Environment Research Council (NERC) Vocabulary P06:
  https://vocab.nerc.ac.uk/search_nvs/P06/
- National Environment Research Council (NERC) Vocabulary P09:
  http://vocab.nerc.ac.uk/collection/P09/current/

6.6. References

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7. PLATFORM 3: FERRYBOX

- How to use this Handbook

The Handbook is intended for a wide and diverse audience. It allows quick and easy access to the most appropriate sections. All readers are encouraged to read this introduction and the table below will help you decide which sections are likely to be most relevant to you.

Audience	*Recommended sections*
FerryBox Operational managers, M&O staff, FerryBox technicians, Coastal Ocean Observing System managers	7.2, 7.3 Platform Description
FerryBox Operational managers, M&O staff, FerryBox technicians, manufacturers	7.4 Sensor(s) and integration into the platform
Marine Data Managers, FerryBox data users, trainers, students	7.5 Data and Data Management Methods for data collection from platforms

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7.1. Introduction

The concept of FerryBoxes was developed in Europe in the 1990s, with the idea to use ships of opportunity to obtain measurements of key ocean variables, like temperature, salinity, and algae in surface waters [Petersen, 2014]. These systems are versatile and allow for combining diverse sensors, and also for in-situ sampling of specific compounds like phytoplankton, nutrients, contaminants and microplastics [Petersen and Colijn, 2017]. FerryBoxes have now been developed in well-established and mature observing platforms [Ainsworth, 2008; Petersen and Colijn, 2017].

7.2. Platform Overview

7.2.1. Purpose

The measurements FerryBoxes produce are essential for increasing the amount of observations in coastal seas (and the open ocean) to be able to capture variabilities on different temporal and spatial scales [Lips and Lips, 2017, Macovei, et al, 2021a]. This is helping to assess trends in surface ocean chemistry for example [Macovei, et al, 2021b], which is essential when attempting to work out carbon budgets for coastal regions. FerryBoxes have been used successfully for obtaining high-quality surface pCO_2 measurements, and studying trace gas dynamics in upwelling regions, phytoplankton bloom dynamics in coastal seas and extreme events [Lips and Lips, 2017; Raateoja, et al, 2018;

Jacobs, et al, 2021; Macovei, et al, 2020; Kerimoglu, et al, 2020]. Ferrybox data can also be used for operational monitoring of the state of coastal areas and various events, such as algal blooms, and for informing the public about them, e.g. [Haraguchi, et al, 2021].
While the term "FerryBox" may be interpreted to mean the observation system is for ferries only, the instrumentation may be used on all types of vessels, and identical systems may also be used in stationary platforms. The advantages of ferries is that they have repetitive routes which then allows systematic observations to monitor water surface trends.
An example of some routes operated in European Seas are shown in Table 7-1. Data are typically transferred once a ship reaches port and a stable connection can be established, or using satellite connection. At Hereon, a subset of data of the main parameters and log files are transferred to the dataserver via an http transfer. The larger complete raw data files, which store all information and housekeeping parameters are downloaded during regular maintenance.

Table 7-1: Some FerryBox operated in European waters. Table is an updated subset from table in Petersen and Colijn, 2017, pp.12-13.

Institution	Ports	Platform	Parameters (Table 3.3.2.1)	Website	Start of Operation	Route Frequency
AWI	Svalbard	Stationary Platform	1-6	https://www.awi.de/en/science/biosciences/shelf-sea-system-ecology/main-research-focus/cosyna.html	2012	365/24
HCMR	Herakleion - Peiraues	Blue Horizon	1 - 6	www.poseidon.hcmr.gr	2002	daily
Hereon	North Sea	Lysbris Seaways	1-7, pCO2	www.cosyna.de	2007	2 weeks - 1 month
Ifremer	Portsmouth-Santander-Plymouth-Roscoff-Cork (St Malo)	MV Pont-Aven	1-5,7			
IMR	Bergen-Kirkenes	MS Vesterålen	1,2,4		2006	11-day roundtrip
INSTM	Tunis-Marseilles, Tunis-Genoa	Carthage	1-6, pCO2, sound velocity		2016	
MSI/TUT	Tallinn - Helsinki	MS Silja Europa	1,2,4,5, pCO2; nutrients	http://ferrybox.msi.ttu.ee	1997-2019	daily
NIVA	Oslo - Kiel	MS Color Fantasy	1,2,4,5,7, cyanobacteria, nutrients, irradiance, radiance	www.ferrybox.no	2008	daily
SYKE	Helsinki-Travemünde	Finnmaid	1,2,4,5,7, nutrients, Phycocyanin	https://www.marinefinland.fi/en-US/The_Baltic_Sea_now/Automatic_observations_from_ships	1993	daily

7.2.2. Description

FerryBoxes have evolved with a set of standard sensors to a mature observational system [Petersen and Colijn, 2017]. The system includes inflow and outflow valves, through which water is pumped to a series of sensors, which may vary depending on the desired application. A debubbler helps to reduce bubbles (see Fig. 7-2, Petersen and Colijn, 2017). The standard parameters measured by the FerryBox are temperature (both at the inlet and in the FerryBox system itself), salinity, dissolved oxygen, chlorophyll fluorescence, and turbidity. All FerryBox systems also collect supporting data for geolocation and time that includes GPS latitude and longitude as well as date and time. Some additional performance-related data can also be collected such as flow rate, pump on/off, cleaning cycle on/off, and cabinet or room temperature. Many systems now have expanded capabilities of measuring pCO2, pH, fluorescent dissolved organic matter, algal classes and more recently microplastics sampling. Despite the diverse FerryBox system designs - which can involve different pumps, plumbing, electronics and computers - FerryBoxes tend to use similar sensors for measuring the above-mentioned essential ocean variables. For salinity and temperature, SeaBird SBE38 and SBE45 sensors are commonly used. Dissolved oxygen optodes are generally used in FerryBoxes and commonly used models are manufactured by Aanderaa and RBR. For chlorophyll a, fluorometers from TriOS, Chelsea, WetLabs, and Turner Designs are used. And for turbidity, AML, WetLabs, and Turner Designs turbidity sensors have been commonly used. In general, any commonly used cylindrical form-factor sensor can be used in a FerryBox with installation in a flow chamber or flow cell that is connected in series to other sensors.

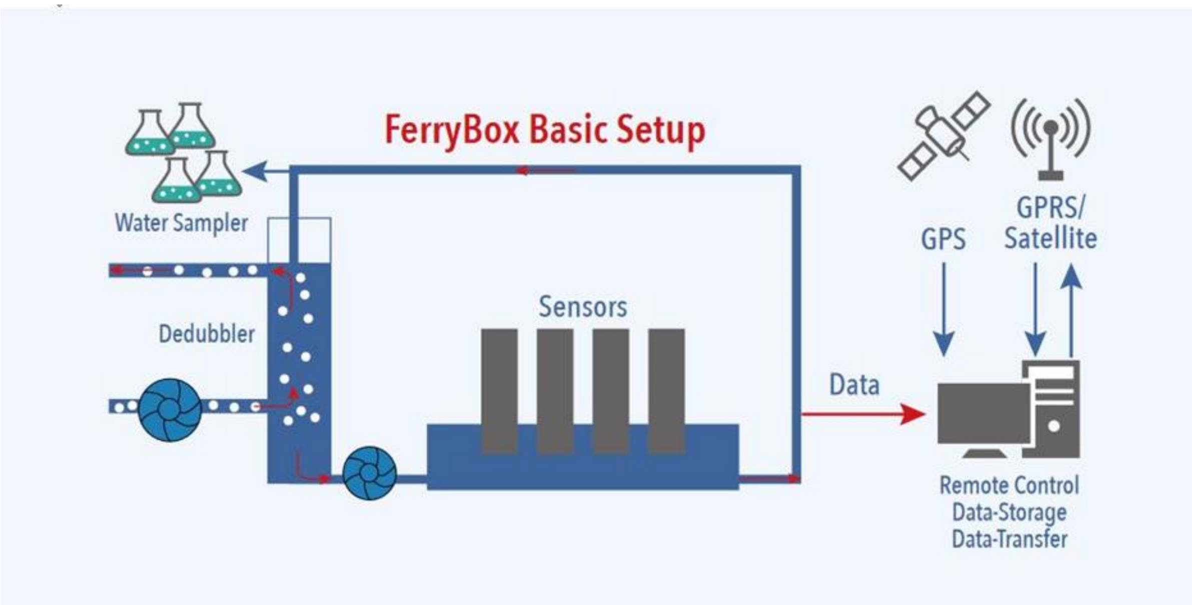

Figure. 7-1: Schematic diagram of a FerryBox flow-through system. Originally published as Figure 1.1 in Petersen and Coljin, 2017.

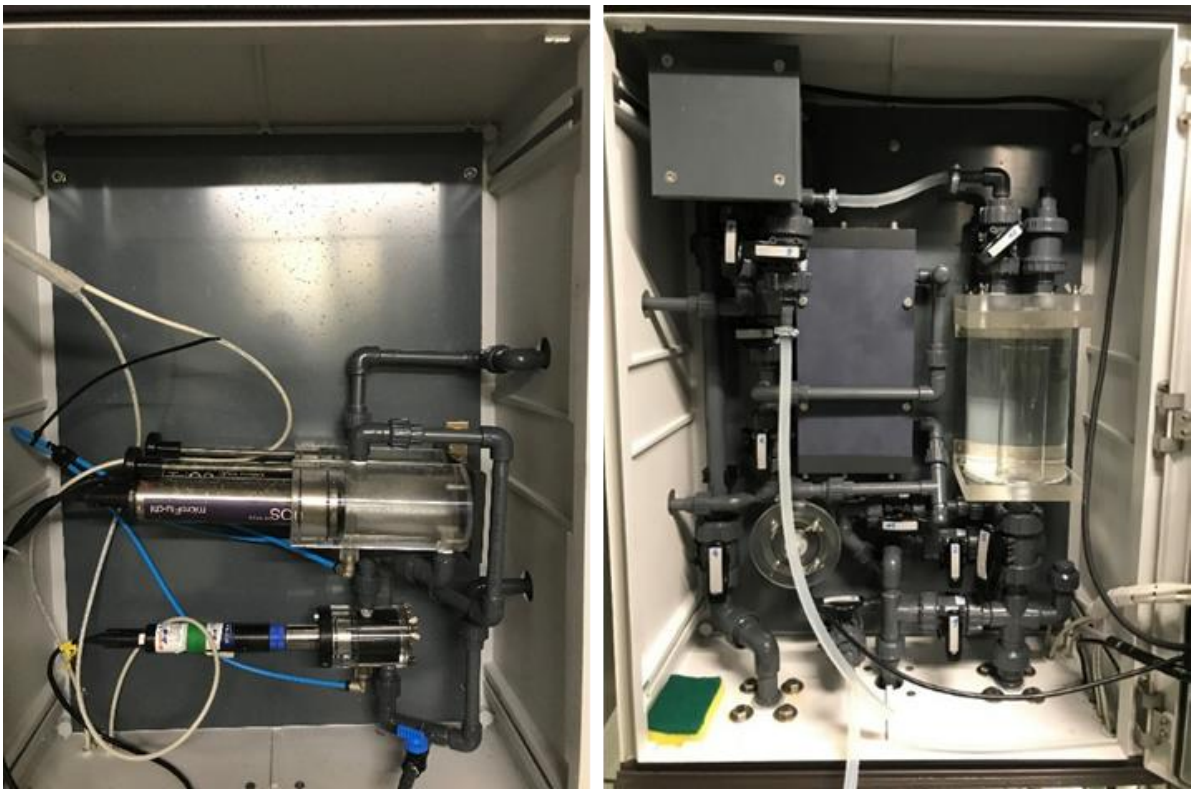

Figure 7-2: NIVA FerryBox. Left panel - optical/fluorescence sensors and flow cells; right panel - clear cylinder = debubbler, gray rectangle in center = SBE45 CTD, clear circle below SBE45 = oxygen optode:

7.3. Detailed platform design

7.3.1. Design and functionality of platform

At present, there is no standard FerryBox system used by JERICO-RI partners and the wider European FerryBox community. There are several commercially available FerryBoxes available for purchase from SMEs including 4H Jena (https://www.4h-jena.de/en/maritime-technologies/flow-systems/ferrybox/) and SubCtech (https://subctech.com/oceanpack-ferrybox_underway-system/). Several other SME's have been producing FerryBox-like packages including Aanderaa SOOGUARD (https://www.aanderaa.com/media/pdfs/b188-sooguard-ferry-box-system.pdf), Flydog Marine Flybox (https://www.flydogmarine.com/products/), and Undersee FerryBox (http://undersee.io/water-data-acquisition/). Some FerryBoxes are also custom fabricated, such as the NIVA FerryBox system and SYKE Algaline system. The diversity in FerryBox systems is for several reasons including, but not limited to, relatively open source concepts in terms of system design, some requirements for miniaturization to fit on certain ships of opportunities (e.g., sailboats), relatively large and spacious setups for easy access and maintenance/repair, customizable and modular boxes to enable customized installation on different ships (i.e. some ships have space in their engine rooms that are not always standard in size or footprint), all-in-one packages that generally promote user-friendly operations but often with some shortcomings relative to customization. Previous JERICO activities for FerryBox systems, a lot of information which is still relevant , can be found at [Petihakis, et al, 2012; Hydes et al 2014; Haller, et al, 2015] . The information provided includes system descriptions, calibration guidance and best practices for operations and maintenance. Detailed design information is best gained through examination of system and component drawings. For commercial systems, the detailed design may exist in manuals, some of which may have limited distribution. For custom systems, the descriptions may exist as well, but could be very lengthy and in customized formats.

FerryBoxes are installed on ships of opportunity and attached to a fixed depth inlet that is typically around 5 m depth. This requires an inflow and outflow valve to be installed through the hull of the vessel. This means that the seawater that is pumped through the FerryBox is generally limited to the surface mixed layer where most primary production and air-sea gas exchange takes place. This is also the depth suitable for remote sensing validation. Since the platform is opportunistic, observations are made along routes used for other purposes, often based on shipping industry applications. This includes regular/repeating shipping routes for container ships and regular/repeating commuting or tourist routes for passenger/cruise ships. Often, adjustments in the regular/repeating routes occur, depending on shipping logistics, changes of shipping companies or other operational reasons. FerryBoxes also provide underway measurements on some research vessels where cruises have specific research interests,. Also, FerryBoxes have been deployed on cruise ships (ex. FerryBox deployment on *Mein Schiff 3* until 2020), which travel to different parts of the World.

Seawater is pumped through the FerryBox system and data is collected with a GPS and date/time stamp throughout the voyage. Measurements are recorded at fixed time intervals, typically at each 10-30 seconds, but practically any interval may be selected. Since FerryBoxes are pumped systems, water is typically delivered to the instrument setup, where sensors are placed in sequence (Figure 7-1). Therefore it is essential to provide enough sample water flow to reduce residence time in the FerryBox, and minimize the effect of potential temperature warming and influence of pumping on dissolved gases before measurements take place. Flow-rate is therefore an essential housekeeping parameter, and required flow-rates are system specific, varying between 4-20 L min^{-1}.

Sensors are typically calibrated in the lab before deployment and periodically during operation, and validated using secondary sensors (e.g., Traceable thermometers for temperature), secondary standards (e.g. used for some fluorometers) and discrete samples analyzed using laboratory instruments that include: salinity samples measured with a Portasal, chlorophyll a samples extracted in solvents and measured via HPLC, spectrophotometry or fluorometry, and turbidity measured using a turbidity meter. Discrete samples can be taken by researchers accompanying the FerryBox along a route or at times also collected by a trained crewmember. Some FerryBox systems are equipped with refrigerated autosamplers (e.g., ISCO samplers with 10 or 24 - 1 L bottles) that can take samples at multiple pre-programmed points along a route to provide heterogeneity in validation samples and later collected and processed at port. The validation samples can later be matched to sensor data by date, time, and location.

7.3.2. Maintenance

The pump supplying seawater to the FerryBoxes is typically turned off when the ships are in port (to prevent pumping in contaminated or high sediment harbour waters), and the pump is automatically switched on when the ship leaves harbour using GPS fencing, ship speed, or both GPS fencing and ship speed as an indicator that the ship is outside of the harbour. Upon arrival at the ship's destination harbour, GPS fencing and/or ship speed is again used to turn off the pump. While deployed at sea, there is generally automated and manual maintenance of FerryBox systems. For automated maintenance, usually when the ship is in harbour and the FerryBox is not making measurements, the plumbing system is flushed with freshwater, acidified water or detergents, or compressed air is used, in an effort to reduce biofouling and mineral deposits on optical surfaces. This procedure can be automated with electronically actuated solenoid valves, but can also be performed manually when someone is physically present. Some sensors also have automatic brushes to remove the buildup of fouling on optical surfaces (e.g., Turner Designs C3).

Manual maintenance typically occurs during visits to the FerryBox when the ship is at port and entails the removal of sensors from their flow cells and brushing/wiping/cleaning the flow cells and optical surfaces to remove fouling. Manual cleaning (e.g. ethanol, deconex and tissue paper) and checking of the optical instruments is performed. The calibration of the pH sensor (glass electrode) is controlled by buffer solutions. The fluorescence sensors may be checked by a solid fluorescence standard, which at least will be an indicator for the drift of the sensor over time. Some sensor flow cuvettes are designed for using high-pressure air to clean the sensor optics. NIVA uses such a system. In every harbour, the pressurized air blows on the optics preventing biofouling to attach to the optics. For the Norwegian routes this means 1 – 4 cleanings per day. Additional manual cleaning is usually needed, though. Currently there is no FerryBox-specific set of best practices for cleaning procedure, mostly due to the versatility of the setups. In general, cleaning of individual sensors follows the best practices indicated for each sensor.

The FerryBox tubings, pipes and valves should be inspected visually for contamination (i.e. biofouling) and leakages. If needed, they are cleaned mechanically using a tissue and distilled water. During the maintenance, the whole system is additionally washed with freshwater and the bottles of chemicals are checked for refills if necessary. Some extreme fouling also necessitates the use of brushes or cleaning rods to dislodge biofouling (e.g., bivalves) from the inlet/outlet and other pipes. Occasionally the tubes and pipes need to be replaced (see Figure. 7-3).

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

Figure 7-3: Examples of biofouling in intake tubing (left image : mussels, barnacles) and debubbler (right image : barnacles growth 2 weeks after cleaning) at Cuxhaven Stationary FerryBox, located at the mouth of Elbe Estuary. Image courtesy of Hereon (H. Rust, M. Gehrung).

Depending on the ship and operator, sensors are periodically removed to be calibrated either in-house or returned to the manufacturer for calibration. It is often beneficial to carry out calibrations of multiple sensors of the same type at the manufacturer, both for efficiency purposes and lower shipping costs, as well as to ensure complementarity in calibration solutions and procedures.

7.3.3. Deployment and recovery

Ferryboxes can be deployed on ships of opportunity or at fixed stations, for example in containers placed near the source waters. A detailed list of FerryBox Routes in Europe (updated up to 2019) with the respective operating institution can be found on the FerryBox TaskTeam website (https://ferrybox.org/routes_data/routes/table_of_routes/index.php.en), alongside a list of FerryBox equipment used in different deployments. This list is not exhaustive, considering that FerryBox operators update FerryBoxes if new sensors and parameters are included, or removed.

One requirement for the deployment site is to have sufficient power to operate FerryBoxes more or less continuously. The concept of FerryBox was developed to be operated in engine rooms of ships, where electricity is typically not limited. More recently, smaller versions and mobile FerryBoxes (https://www.4h-jena.de/en/maritime-technologies/flow-systems/pocketferrybox/) have been developed, which allow for deployment on small boats, places with reduced space (smaller engine rooms), measurement poles (short-time deployments). For example a deployment of a Pocket FerryBox (4H-Jena Engineering, Kiel, Germany) allowed for water column measurements in a small lagoon at the German-Polish border (Figure 7-4). A mobile and miniaturised FerryBox (termed a μFerryBox) was designed and deployed by NIVA during the COVID-19 pandemic when passenger ships were unpredictably in/out of operation due to reduced passenger loads and other ship company logistics (Figure 7-5).

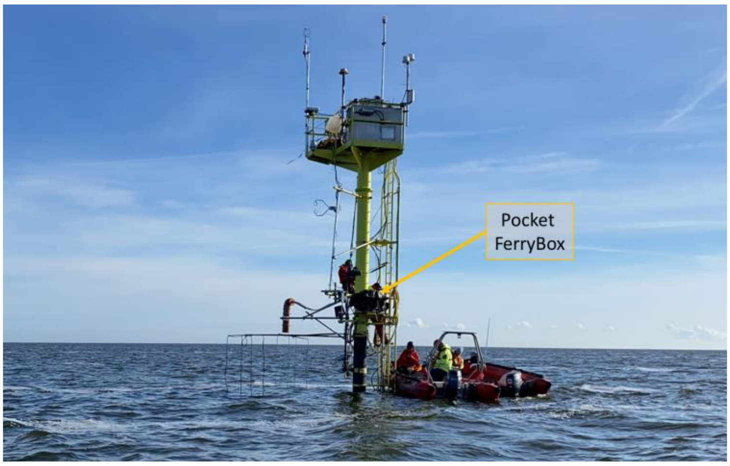

Figure 7-4: Deployment of the mobile Pocket FerryBox in the field on a measurement pile during a Hereon field campaign, October 2021.

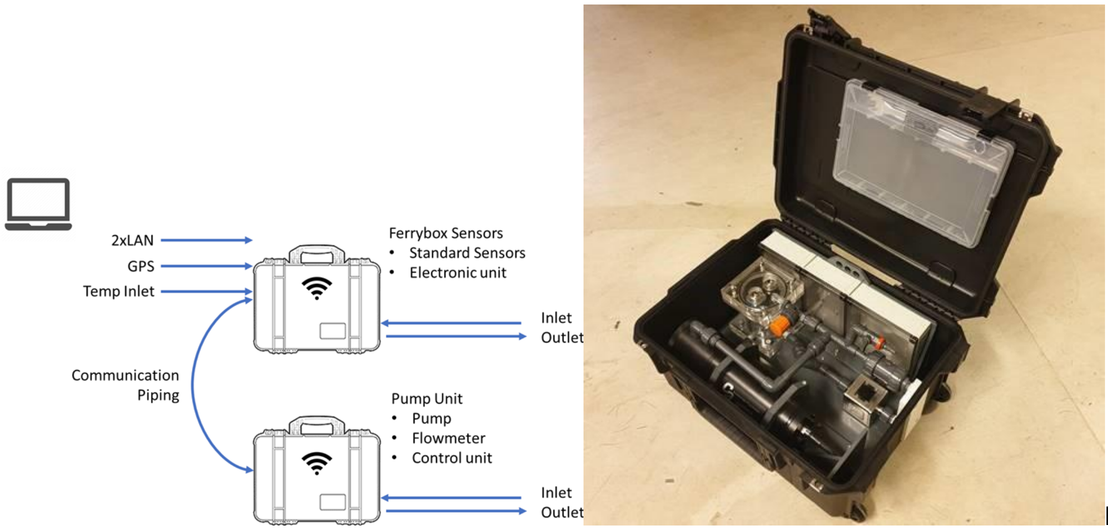

Figure 7-5:. Left panel: schematic design of NIVA's µFerryBox that includes two pelicases (with wheels) that are small and light enough to be checked in baggage on commercial flights. One pelicase includes GPS, electronics, and standard sensors. The second pelicase includes a pump, flow meter, and control unit. Both pelicases have water inlet/outlet and communication cables. Each pelicase weighs less than 20 kg for easy carrying/rolling, and the systems can be quickly moved from one ship to another and deployed as long as electricity and water connections are available. Right panel: photo of the pelicase that includes GPS, electronics, and standard sensors.

Since FerryBoxes are a system operating a number of sensors, the sensors and different parts of the system can be upgraded, or replaced, including the computer/operating system, valves, tubing, sensors, pumps, etc. Some systems have run on platforms over more than 10 years for example. If a FerryBox needs a major upgrade, including changing sensors, tubing and flow paths, and upgrading a computer for example, this can be done by removing the whole system, and closing and securing the inflow/outflow valves on the platform. Alternatively, sometimes ships of opportunity change routes or are no longer operated, so the FerryBoxes onboard can no longer be maintained and serviced, or operated. In this case, the whole FerryBox can be removed, and placed on another platform, if such a platform is available.

7.3.4. Analyses of platform performance

At this time there are no KPIs established for FerryBoxes

7.3.5. Uncertainties in observations

FerryBox measurements are relatively robust, and systems are serviceable during frequent harbour visits. However, the method involves a number of uncertainties due to the location of the equipment on board, access to the equipment, the timing and route of the voyages, the measurement technologies itself, and of course, quality of the maintenance.
Especially in commercial ferries, the position of the FerryBox system onboard is determined by the ship's personnel. This includes, besides the actual site of the FerryBox system, also the position of the water inlet and length of piping prior to the sensors. Therefore, some heating of sample water may take place between inlet and FerryBox, though this may be compensated by adding additional temperature sensors (or using hull temperature sensors). However, some other variables, like oxygen, may also be affected by heating.
The exact water layer sampled is dependent on the positioning of the inlet and the shape of the hull. It may be difficult to verify which layer exactly is sampled, and it may vary due to ship speed. Depth of inlet also depends on ship rocking and load. It would be best if the inlet is positioned in such a way that water rinses around it all the time. In ice covered seasons the crushed ice may cause issues with water flow and the inlet may need to be protected.
For commercial ships, the ship routes and timetables may change at short notice and affect the access to the FerryBox equipment, making the maintenance difficult. As well, there may be other inconveniences affecting the use and service of FerryBox systems, including docking periods, changes in safety regulations in ships or harbour areas, changes in personnel with whom the activities have been agreed, strikes, storms affecting timetables, greywater outlets, power outages and other technical failures.
The normal sensor uncertainties are, of course, inevitable. Sometimes sensors are designed for other types of uses (e.g. deployments in water) and they are customized for flow-through systems. This may bring unwanted biases to measurements e.g. if the flow chamber affects the observations, or if it is not functioning properly, when installed in pressurized systems. A well known issue is condensation of water vapour in optical lenses, when the sensor body is in a warm engine room but the sensor head is continuously flushed with cold sample water. All these biases may be circumvented by rigorous testing of systems and planning well ahead.
If automated samplers are used to validate sensors or for other studies, the method of sampling may bring uncertainties. Typically these automated samplers are cooled, like refrigerators, but depending on the route and location of sampling stations, the samples may stay for prolonged times (hours-days) inside open sampler bottles until processed in laboratories. Some variables are more vulnerable to distortion during such long storage, especially the organisms having short lifespans, or volatile compounds.

Sensor biofouling, or overall lack of maintenance, is one of the key factors creating uncertainties in FerryBox measurements. It needs to be underlined, that these automated and continuously operated systems also require continuous care, during productive seasons

a once-per-week to once-per-every-other-week manual cleaning may be needed. The cleaning frequency depends largely on the environment where these systems are operated: for example, at a tidal station, like Cuxhaven Stationary FerryBox in Germany, in the Spring to early Fall, different organisms can grow in the tubing and affect the flow, thus influencing all parameters, or biofouling can affect specific sensors (dissolved oxygen or fluorescence sensors for example). This requires regular cleaning every 2-3 weeks during the growing seasons, and every 4-6 weeks during the rest of the year, with a more extensive cleaning and/or tube replacement 2-4 times a year. For Ships of Opportunity [SOO], which travel in open waters like the North Sea, the Mediterranean Sea and North Atlantic, and where automatic cleaning is available, FerryBoxes can also be operated over weeks or even months without the need for manual cleaning. For example, during 2020-2021, CoVid-19 restrictions limited access to the *CV Lysbris Seaways* over several months. Nevertheless, during this time the FerryBox operated well, and produced stable reliable measurements.
Some specific uncertainties are related to frequent routes and timetables, as observations are made at the same place and time every day or week (regular routes/timing). This has been noted to give bias for carbonate system measurements in biologically active systems [Honkanen, et al, 2021] and another example is a well-known diel variability in Chl a fluorescence due to non-photochemical quenching, making the signal difficult to interpret.

7.3.6. Issues

The issues have been covered in the previous sections. To summarize, one limitation of FerryBox systems is that they provide only data on surface water properties and, if necessary, have to be complemented with depth profiles obtained by conductivity, temperature and depth (CTD) measurements from research vessels or buoys. Another disadvantage is that a SOO cannot stop along its route to sample additional stations and depths, as a research vessel is able to. Also, often Ships of Opportunity change routes and may not be available in a certain region of scientific interest [Petersen, et al, 2011]. One challenge is the changes in vessel routes, which may reduce the value of repetitive sampling. Of course, only the regions along the routes are observed, therefore information from the surrounding regions should be assessed using other information, for example satellites for large scale chlorophyll patterns, or models for general and local circulation patterns [Callies, et al, 2022].

7.3.7. FerryBox Platform best practices and standards

- Best Practices

In the JERICO summary reports on FerryBox Systems [Petihakis et al, 2012; Hydes et al, 2014; Haller, et al, 2015], several detailed best practices for FerryBox systems are given. FerryBox WhiteBook [Petersen and Colijn, 2017] is the key reference to be studied while planning new FerryBox operations.

Table 7-2: FerryBox - Platform best practices

Best Practice /title	refer in Annex I	Notes

Report on best practice in conducting operations and maintaining: D 4.4. (Version 1 - 27/02/2012). DOI:10.13155/49741 [Petihakis, et al, 2012]	*23*	
*FerryBox Whitebook, EuroGOOS DOI: http://dx.doi.org/10.25607/OBP-1002 [*Petersen and Colijn, 2017]	*32*	
*D3.1 Report on current status of Ferrybox [*Hydes et al, 2014]	*6*	
*Conclusion report on FerryBox systems D3.5. Version 1.1. [*Haller, et al, 2015]	*38*	

7.4. Sensors and integration into platform

7.4.1. General description

Sensors used in FerryBoxes vary, depending on operator preference, size requirements, energy consumption and sometimes age of each FerryBox. One large advantage of the FerryBox is that, depending on how it is made and programmed, it can accommodate many different types of sensors and in a modular manner - technology updates are possible.

7.4.2. Detailed description

Instrument companies like 4H Jena have a typical set of parameters (https://www.4h-jena.de/en/maritime-technologies/flow-systems/ferrybox/), but most likely, they can provide a setup required by the FerryBox operator. Some of the sensors used in FerryBox operations are listed in Table 7-2, but this list is not exhaustive.

Table 7-3: A list of some sensors, used to measure EOVs in FerryBoxes, and information on accuracy, precision and potential sources of bias and uncertainty. Table was modified from Table 1 in [Petersen, et al. 2018]

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

Parameter	Range	Unit	Accuracy	Precision	Uncertainty/ Bias	Instrument	Manufacturer
Water Temperature (1)	0 to 50	°C	0.1	0.01	Potential warming inside tubing (max 0.5 °C)	Excell ETSG2	Falmouth Scientific Inc., USA
Water Temperature (1)	-5 to 35	°C	0.001-0.002		Potential warming inside tubing (max 0.5 °C)	Sea-Bird SBE45 and SBE38	Sea-Bird Scientific, USA
Salinity (2)	0 to 50		0.02	0.001	Potential drift with fouling	Excell ETSG2	Falmouth Scientific Inc., USA
Conductivity (2)	0 to 7	S/m	0.0003		Potential drift with fouling	Sea-Bird SBE45	Sea-Bird Scientific, USA
Dissolved Oxygen (3)	0 to 500	µmol L-1	5-8%	1	Potential Drift and initial offset	Optode (3830,..)	Aanderaa/Xylem, Norway, USA
Chlorophyll Fluorescence (4)	0 to 200	µg L-1	10%	0.5	Changing fluorescence yield, biofouling	SCUFA/ C3	Turner Designs
Turbidity (5)	0 to 50	NTU		0.05	Offset due to small bubbles	SCUFA/ C3	Turner Designs
pH (6)	7.5-8.5	pH (total scale)	0.003	0.001	Temperature, particles, optimisation of optics, purity of indicator dye	Custom spectrophotometric flow through sensor	NIVA

CDOM Fluorescence (7)	0-1500	ppb Quinine Sulphate	0.1		biofouling	C3	Turner Designs

7.4.3. Sensor calibration

Because the FerryBox has a number of instruments for Essential Ocean Variables (EOV) included in the FerryBox setup, FerryBox users often rely on instrument calibration provided by manufacturers, according to instrument specification. Examples include Seabird SBE45, TriOS, WetLabs optical sensors, which should be calibrated and checked every 1-2 years. In addition, external checks like Winkler titrations of oxygen samples can help to check performance of optodes, which can be deployed over longer time periods. In some regions, like among the Baltic Sea FerryBox operators, a joint annual calibration of optical sensors for chlorophyll, CDOM and phycocyanin is performed to secure consistency of measurements [Seppälä, et al, 2021].

7.4.4. Uncertainties in observations

Uncertainties in sensor-based observations can be due to various factors that are due to the sensor itself and also to external factors such as the measurand, especially if it is biological in nature. Accuracy and precision for EOVs measured by different sensors are listed in Table 7-3. In some cases, only one of the two metrics are available from the manufacturer.

7.4.5. Quality Assurance methods

The quality of data collected by sensors is dependent on calibration (section 7.4.3), maintenance (see previous section), and on validation checks and samples. For sea temperature, reference thermometers are used to periodically check the performance of the temperature sensor in CTDs to ensure that the sensor is functioning properly and the calibration is still good. For virtually all other sensors, discrete samples are collected at the same time as the sensor is measuring seawater. These samples are then brought back to the laboratory to measure the relevant variables using laboratory instruments that have higher precision/accuracy. For example, discrete samples are filtered, extracted, and measured on laboratory spectrophotometers or fluorometers for validation of chlorophyll a fluorometer sensors. Or discrete samples are collected and analysed via Winkler titration for oxygen concentration for validation of oxygen optodes. Some sensors, like fluorometers, can also be checked on board using solid standards that fluoresce at certain wavelengths. However, these are often considered qualitative assessments and not quantitative.

7.4.6. Issues

In FerryBox systems sensors may need to be adapted to measure appropriately in flow-through conditions. Typically this means purchasing or manufacturing flow-caps and checking that these do not cause interferences in the measurements. Some sensors may be affected by the pressure in the tubings and one may have to come up with alternative ways to measure.

FerryBoxes need to be visited on a regular basis to ensure high quality measurements. As sometimes FerryBox systems and sensors are located in not so easily accessible corners of machine rooms, all dedicated reference measurements are not easy to perform on site.

7.4.7. Sensor best practices and standards

The sensors used in FerryBox systems do not differ from those used in other platforms, rather, most sensors can be used interchangeably in various platforms. Therefore also no separate Best Practices for sensors in FerryBox systems exist. Best Practice documents, like [Möller, et al, 2019] for advanced sensors should be used.

7.5. Data and data Management methods

7.5.1. Description of data

FerryBox systems provide data of a number (about 20) Essential Ocean Variables (EOV), along with housekeeping parameters in surface coastal, estuarine and open ocean waters. The standard EOVs observed by FerryBox systems include temperature, salinity, dissolved oxygen (concentration and % saturation), pH, chlorophyll fluorescence, and turbidity. Additional parameters can be added, depending on scientific interest and applications. These include partial pressure of carbon dioxide ($p\mathrm{CO_2}$), coloured dissolved organic matter (CDOM), nutrient measurements (UV, lab-on-chip, wet-chemistry methods), total alkalinity, microplastics (filtering setup), cyanobacteria pigments, algal classes [Petersen, et al, 2008; Lips and Lips, 2008; Petersen and Colijn, 2017; Petersen, 2014; Voynova, et al, 2019; Assmann, et al, 2011]. Housekeeping parameters include status of the FerryBox, flow-rate, speed of vessel, timestamp, coordinates, quality flags, and statistical information. The statistical information includes estimates of minimum, maximum, variance and counts [Petersen and Colijn, 2017].

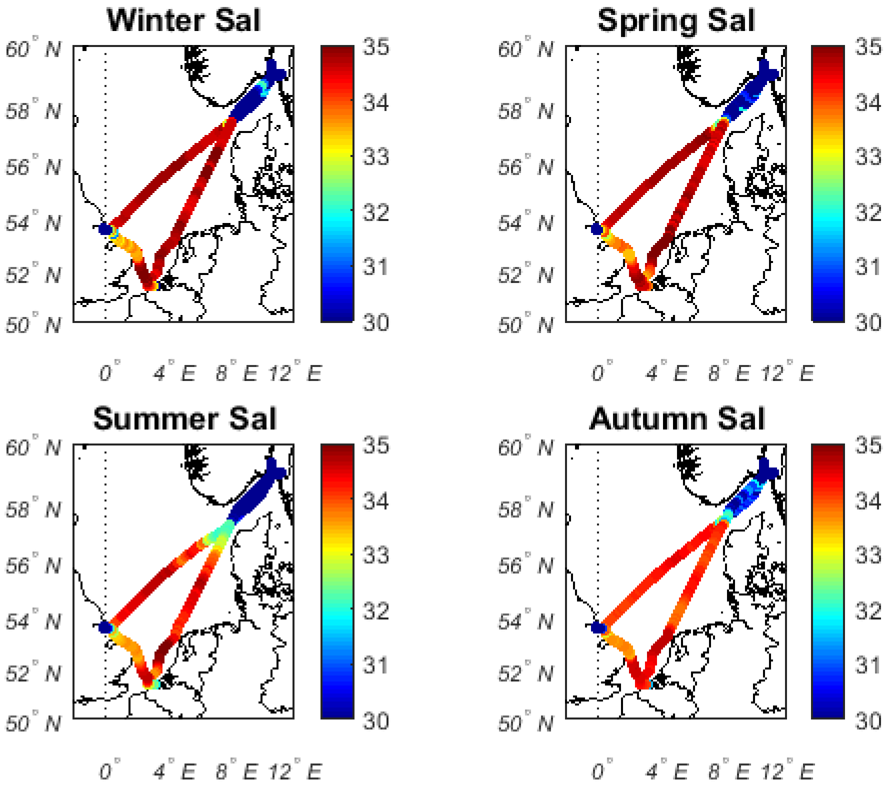

Figure 7-6: Seasonal plots of salinity in the North Sea in 2014 along the SOO Lysbris Seaways route between Immingham (UK) – Moss/Halden (NO) – Zeebrugge/Ghent (NL).

Depending on where FerryBoxes are deployed, data acquisition frequency can vary. In an underway system, where a research vessel or a ship of opportunity (SOO) crosses different regions along its route, more frequent sampling is required, sometimes down to a few seconds to properly capture regional variability [Lips and Lips, 2008; Macovei et al, 2020]. This allows capture of environmental variability, such as seasonal, regional and water mass changes (Figure 7-6). At fixed stations, sampling rate may be lowered, but the environmental variability should be properly sampled. At a tidal station for example, where tidal, daily, current variabilities exist, sampling should be done at least every 2-3 hours, preferably every 20 minutes to 1 hour [Voynova, et al, 2017].

Since the beginning of European FerryBox activities in the Baltic Sea in the 1980s, and later, on a European level with the FP5 project "FerryBox" (2003-2005) [Petersen, et al, 2007], there has been an increasing number of FerryBox lines as well as ongoing activities on harmonization of operation [see FerryBox White Book, Petersen and Colijn, 2017]. However, progress in visibility and accessibility of the FB data has been slow, even if long-term FerryBox data sets exist, especially in the Baltic Sea and North Sea. These data sets are often available upon request to the data originator and mostly based on files (ASCII or NetCDF) [Petersen and Colijn, 2017]. An effort has been made to make ferrydata.hzg.de, a Hereon COSYNA-supported data portal available for the European FerryBox community. Even though many FerryBox operators do provide data there, and this data portal is considered as the EuroGOOS FerryBox TaskTeam data portal, Figure 7-7, this is still under discussion with the community. Many FerryBox operators also directly report data to international and European data portals like EMODnet and Copernicus Marine Services.

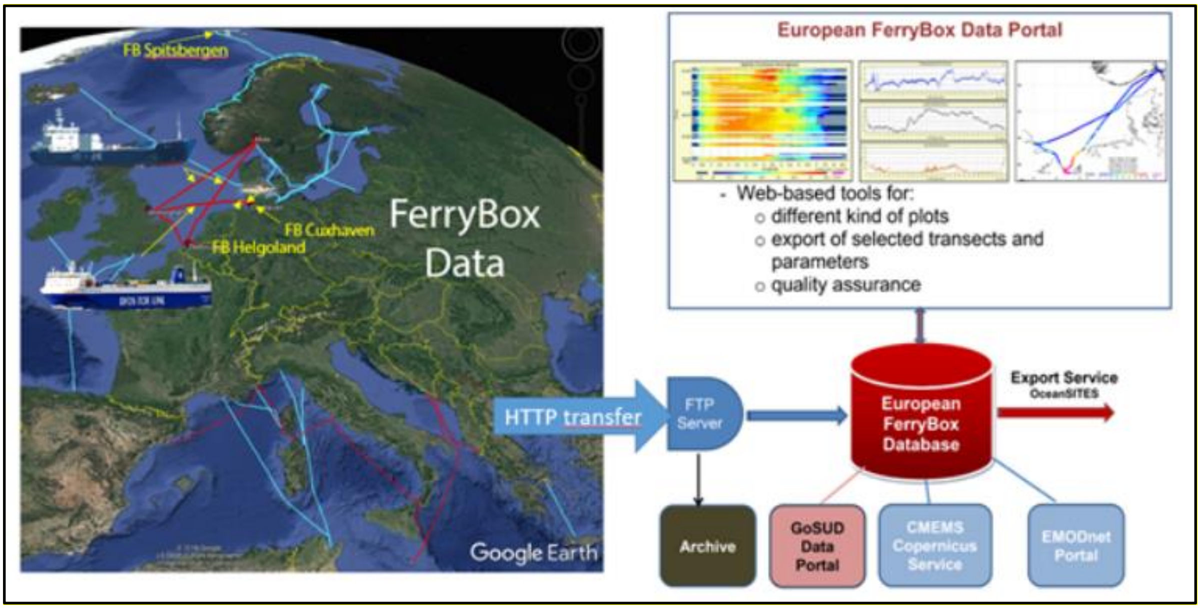

Figure 7-7: FerryBox Data Portal data transfer and dissemination.

7.5.2. Data value chain: from acquisition to delivery

Data are stored on a FerryBox computer, typically using LabView or Python system controls. The commercially available FerryBox from 4H Jena Engineering has a LabView system, similar to the one used in Hereon. SMHI operates using a python-based system [Petersen and Colijn, 2017]. All parameters are filtered / flagged by housekeeping parameters. These include status of the FerryBox, flow rate, speed of the vessel (for moving platforms).

Automated transfer of data and quality checks from processing allows for import into the Hereon FerryBox Database (ferrybox.org, http://ferrydata.hereon.de for fixed routes and tsdata.hereon.de for fixed stations). Working files contain metadata including sensor type and identification, data quality flags, range, minimum, maximum, variance, location data, raw values. An example is shown in Figure 7-8. Automated transfer of data and quality checks from processing allows for import into the HZG FerryBox Database (ferrybox.org, http://ferrydata.hzg.de for fixed routes and tsdata.hzg.de for fixed stations).

```
$METADATA
$Project; FerryBox
$Hostname; PC1/R07036-PC1
$DateTime; 2021.12.05 00:00:04
$Filename; CO2FT_A_PCO2_Corr_20211205.txt
$Type; HydroC CO2FT (CO2T-1019-004*4b)
$Formula; Meas=a0+a1*Raw+a2*Raw^2+a3*Raw^3
$Ranges; 1
$Range1.a0; 0.0000000000E+0
$Range1.a1; 10.0000000000E-3
$Range1.a2; 0.0000000000E+0
$Range1.a3; 0.0000000000E+0
$QUALITYBITS
$Bit; Value, Meaning
$0; 1, Unknown measuring value.
$5; 32, Processstatus = unknown.
$6; 64, Processstatus 1 = clean.
$7; 128, Processstatus 2 = standby.
$8; 256, Processstatus 3 = empty.
$9; 512, Processstatus 9 = error.
$10; 1024, Processstatus 8 = undefined state.
$11; 2048, Simulated data.
$12; 4096, Measuring delay.
$13; 8192, Value from zero-cycle.
$14; 16384, Value from flush-cycle.
$INFOBITS
$Bit; Value, Meaning
$0; 1, Unknown measuring value.
$1; 2, Data overflow.
$2; 4, Data underflow.
$3; 8, Device timeout.
$4; 16, Channel mismatch.
$5; 32, Receiverwarning (GPS only).
$6; 64, Lower then 2 satellites (GPS only).
$7; 128, No GPS signal (GPS only).
$8; 256, CRC error (GPS only).
$9; 512, Latitude and longitude are 0 (GPS only).
$10; 1024, Formaterror.
$FORMATS
$1; Timestamp, Date Time; YYYY.MM.DD hh:mm:ss
$2; PCO2_Corr, µAtm; Float
$3; Quality, Flags; Int
$4; MeasCount, Cnt; Int
$5; MeanTime, Sec; Int
$6; Range, MR; Int
$7; Minimum, µAtm; Float
$8; Maximum; µAtm; Float
$9; Variance, Units; Float
$10; Longitude, Deg: Float
$11; Latitude, Deg; Float
$12; Rawvalue, Units; Float
$13; Info, Flags; Int
$DATASETS
$Timestamp  PCO2_Corr   Quality MeasCount   MeanTime    Range    Minimum Maximum Variance    Longitude   Latitude
$Date Time  µAtm    Flags   Cnt Sec MR  µAtm    µAtm    Units   Deg Deg Units   Flags
2021.12.05 00:00:00 469.480000  0   35  55  1   468.860000  470.010000  0.114900    NaN NaN 46948.000000    0
2021.12.05 00:01:00 469.294722  0   36  54  1   468.920000  469.940000  0.073317    NaN NaN 46939.472222    0
2021.12.05 00:02:01 469.399091  0   33  57  1   468.730000  470.090000  0.183421    NaN NaN 46939.909091    0
```

Figure 7-8:. An example of a working file for pCO2 data in December, 2021, with metadata and data descriptions in file header.

- Metadata information

Different types of metadata exist for FerryBox data:

1. Metadata for the sensors stored as SensorML. These metadata from Hereon are stored inside the sensor database of the AWI (https://sensor.awi.de/) which is generally used for German marine data. For example the FerryBox on Lysbris which operates on the route covering large parts of the North Sea is https://hdl.handle.net/10013/sensor.51009c8a-9d2c-4c53-ac7a-615ce4ac3974.

2. Metadata for transects and data stored as ISO19115. These metadata are relevant for the FAIR use of data. The Hereon FerryBox type 2 metadata are stored in ISO 19115-3:2018 format available at https://hcdc.hereon.de/geonetwork/srv/eng/catalog.search.

3. An additional metadata system for type 2 metadata provide OGC Web Feature Services used by the COSYNA data portal CODM. From there you could use the FerryBox data in a findable, accessible and interoperable way to reuse the data.

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- Data policy

There is no common data policy for the FB community, per se. But any H2020 and most national funding dictates that data must be made FAIR via national/European databases.

- Data dissemination

There are currently a number of institutes, which report data according to these requirements, but often this depends on national and institutional requirements. Access to Hereon FerryBox data could be achieved with the help of the COSYNA Data Portal CODM (https://codm.hereon.de/codm) described in [Breitbach, et al, 2016].

7.5.3. Quality Control and Quality Assurance

- Near-Real Time QC

Near Real Time Quality Check is performed after each cruise. File transfer, in general of 500K Data points / week via ftp, is done when a secure connection is established. In general, file transfer can cover about 20 parameters, and 3-6 housekeeping parameters: timestamp, coordinates, quality flags, statistical information (minimum and maximum values, variance, counts).

Near Real Time Quality Check is performed inside the database within one hour after data transfer following the procedures recommended by the EuroGOOS DATA-MEQ working group.

Near Real Time Quality Controlled data (ferrybox.org, http://ferrydata.hzg.de for fixed routes) are communicated to CMEMS Copernicus Service and EMODnet Portal, and exported in NetCDF format to OceanSITES

- Delayed Mode QC

Data for a number of parameters need to be additionally verified using delayed quality controls. These protocols are still under development, and will be further described (concerning the carbonate system parameters for example) in WP2 deliverables. The methods include:

Assessing measurements against multiple sensors in the field. Examples include:

- Temperature
- Chlorophyll fluorescence
- Turbidity

Assessing measurements against laboratory samples for salinity, turbidity, chlorophyll a fluorescence, dissolved oxygen, nutrients. The QC-ed results are then published on Pangaea database. One example is: https://doi.pangaea.de/10.1594/PANGAEA.883824.

Assessing measurements according to calibration data, with necessary pre- and post-calibration applications. Examples include (based on Hereon-specific FB delayed QA/QC):

- *p*CO_2, which includes comparison to standard SOCAT database measurements [Macovei et al, 2020]
- total alkalinity and pH, which includes comparison to collected samples measured in the laboratory [Voynova et al, 2019]. Measurements are standardized using reference materials.
- automated nutrient measurements, which include assessment to additional nutrient samples measured in the laboratory, as well as examination of individual periodic calibrations and check standards. Measurements are standardized using reference Materials.

Web-based tools available at the European FerryBox Database allow for data visualization and help with Delayed Quality Control. These are tools developed specifically for the use of underway observations (Figure 7-9).

Figure 7-9: Visualization tools available at the European FerryBox Database

- Transect Plot I (Figure 7-10), one or more parameter along one transect (one cruise). Flagged data from realtime quality are marked in red

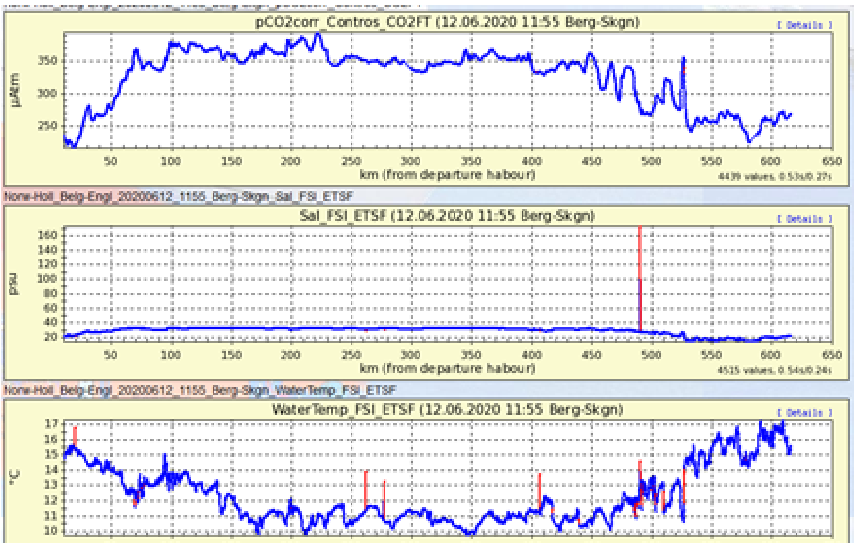

Figure 7-10: pCO2, salinity, temperature along Bergen-Skogn route in June, 2020

- Transect Plot II : one parameter along multiple transects (comparison of repeated measurement)
- Scatter Plot: Hovmöller plot (Figure. 7-11): Plotting data (colour coded) vs. position (e.g. distance, longitude or latitude) and time. Flood event in 2013 was visualized in the North Sea coast.

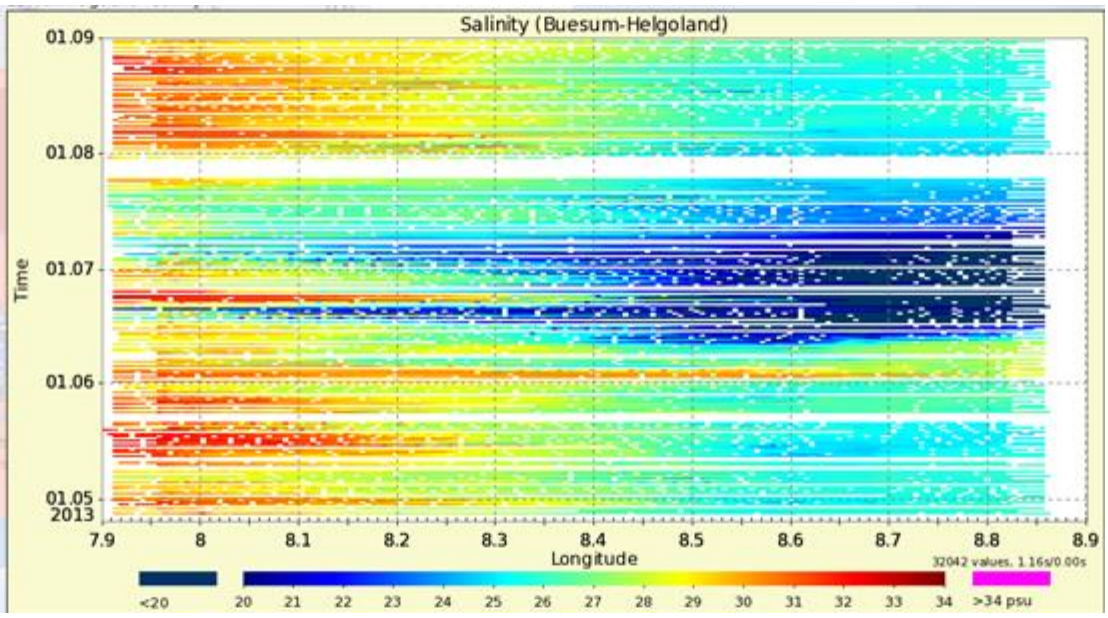

Figure 7-11: Hovmöller plot of salinity in the German Bight. Figure was published in [Callies et al, 2021]

- Map Plot : Plotting data as color-coded information in a map
- Time Series Plot : Time series of one or more parameter at a certain position

From transect plot I it is possible to visualize the data as SOS V2 (https://52north.org/software/software-projects/sos/) using the menu details of the plot. This will lead to a visualization like Figure 7-12 Please note that only http is available.

Figure 7-12: SOS V2 plot of the transect Immingham-Esbjerg (22.01.2022). Shown are the measured data for oxygen saturation in a spatial as well as temporal representation

7.5.4. Issues

Moving platforms can change routes, therefore if a port is not identified, data are not transferred to the database. This requires manual verification, and subsequent addition of ports. One way to solve this would be to use AIS data, with many ports identified.

Data in the database is sorted according to routes, therefore with some limitations, like the necessity to define ports, which are used in the working files. One way is to avoid this, by not predefining ports, which is already in place for FerryBox data from research vessels.

7.5.5. Training materials

A practical exercise how to use the quality assessment implemented inside the European FerryBox Database http://ferrydata.hereon.de during the 7th FerryBox Workshop (https://ferrybox.org/imperia/md/images/hzg/institut_fuer_kuestenforschung/koi/ferrybox/programm.pdf) was given by M. Gehrung and G. Breitbach

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7.5.6. FerryBox - Data best practices and standards

Table 7-4: FerryBox - Data best practices

Best Practice /title	refer in Annex I	Notes
Specifications for a European FerryBox data management system, WP5.3, D5.3. Version 1.1.[Linders, 2017]	14	
Recommendations for in-situ data Near Real Time Quality Control. [Version 1.2] [EuroGOOS DATA-MEQ Working Group, 2010]	31	
OceanSITES Data Format Reference Manual NetCDF Conventions and Reference Tables. Version 1.4 July 16, 2020. Geneva, Switzerland, OceanSITES, JCOMMOPS, 36pp. DOI: http://dx.doi.org/10.25607/OBP-421.2	37	

COSYNA **data management** is based on different **standards** like

- ISO 19115
  https://www.iso.org/standard/53798.html
- INSPIRE Directive:
  https://inspire.ec.europa.eu/
- ISO8601 standard date and time format:
  https://www.iso.org/iso-8601-date-and-time-format.html
- Climate and Forecast Metadata Convention CF-1.6:
  https://cfconventions.org/cf-conventions/v1.6.0/cf-conventions.html
- OPeNDAP
  https://www.opendap.org
- Open Geospatial Consortium (OGC) for access and delivery of geospatial data
  https://www.ogc.org/docs/is
- OGC Sensor Observation Service (SOS) as webservice to access data from the database used for in-situ data, OGC WMS to visualize geodata
- OceanSITES:
  http://www.oceansites.org/docs/oceansites_data_format_reference_manual.pdf
- CMEMS-INSTAC System Requirements Document (SRD):
  https://archimer.ifremer.fr/doc/00297/40846/
- EuroGOOS recommendations for in-situ data Near Real Time Quality Control

https://archimer.ifremer.fr/doc/00251/36230/

The following controlled vocabularies are used as well in the FerryBox data processing:

- National Environment Research Council (NERC) Vocabulary P02: https://vocab.nerc.ac.uk/search_nvs/P02/

- National Environment Research Council (NERC) Vocabulary P07: https://vocab.nerc.ac.uk/search_nvs/P07/

Hereon FerryBox data from Ferrydata or Tsdata could be downloaded using SOS. This web service requires the fixed part

http://sos.hereon.de/sos.py?request=GetObservation&service=SOS

and in addition the dynamic URL parameters:

- offering – the name of the offering (Gothenburg-Immingham for the FerryBox operating on the SOO Magnolia on the route Gothenburg-Immingham)
- observedProperty – in most cases the P02 parameter name. The name has 4 capital letters like PSAL for salinity
- eventTime – begin and end of the data as ISO 8601 format

Putting this together the example URL

http://sos.hereon.de/sos.py?request=GetObservation&service=SOS&eventTime=2022-01-17T20:39:54.579Z/2022-01-18T13:07:54.579Z&offering=Gothenburg-Immingham&observedProperty=PSAL

will show the salinity data of the Magnolia transect starting at 17.01.2022 20:39.

The file responded to the URL above will be:


```
<om:Observation xsi:schemaLocation="http://www.opengis.net/om http://amb25.stccmop.org/schemas/sos/current/sosGetObservation.xsd" gml:id="PSAL">
<gml:description>None</gml:description>
<gml:name>Gothenburg-Immingham</gml:name>
<gml:location>
<!-- geometry containing all tuples in this observation -->
<gml:Envelope>
<gml:lowerCorner srsName="urn:ogc:def:crs:EPSG:6.5:4326">53.0 -5.0</gml:lowerCorner>
<gml:upperCorner srsName="urn:ogc:def:crs:EPSG:6.5:4326">58.2 12.2</gml:upperCorner>
</gml:Envelope> </gml:location>
<!-- Time of response- use TimePeriod for a series of data
-->
<!--  or TimeInstant for a single measurement  -->
<gml:TimePeriod gml:id="DATA_TIME">
<gml:beginPosition>2022-01-17T20:39:54.579Z</gml:beginPosition>
<gml:endPosition>2022-01-18T13:07:54.579Z</gml:endPosition>
</gml:TimePeriod>
<!-- Procedure --><om:procedure/> <!-- the property measured -->
<om:observedProperty xlink:href="PSAL"/>
<!-- Feature Of Interest -->  <om:featureOfInterest xlink:href="None"/>
<!-- Result Structure and Encoding --> <om:resultDefinition>
<swe:DataBlockDefinition> <swe:components name="PSAL">
<swe:DataRecord>
<swe:field name="time"><swe:Time
definition="urn:ogc:def:phenomenon:time:iso8601"/></swe:field>
<swe:field name="latitude">
```

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.


```
<swe:Quantity definition="urn:ogc:def:phenomenon:latitude:wgs84">
<swe:uom code="deg"/></swe:Quantity></swe:field>
<swe:field name="longitude">
<swe:Quantity definition="urn:ogc:def:phenomenon:longitude:wgs84">
<swe:uom code="deg"/></swe:Quantity></swe:field>
<swe:field name="depth">
<swe:Quantity definition="cf:depth">
<swe:uom code="urn:ogc:unit:meter"/></swe:Quantity></swe:field>
<swe:field name="PSAL">
<swe:Quantity definition="PSAL">
<swe:uom xlink:href="urn:mm.def:units#PSU"/></swe:Quantity></swe:field>
<swe:field name="quality flag">
<swe:Quantity definition="SeaDataNet Quality Flag Definition">
<swe:uom xlink:href="http://vocab.ndg.nerc.ac.uk/list/L201/current"/></swe:Quantity></swe:field>
</swe:DataRecord></swe:components>
<swe:encoding><swe:AsciiBlock tokenSeparator="," blockSeparator="|" decimalSeparator="."/>
</swe:encoding></swe:DataBlockDefinition></om:resultDefinition>
<om:result>
2022-01-17T20:45:00Z,53.549791,0.137263,2,30.7159,2|2022-01-
17T20:45:20Z,53.549136,0.139254,2,30.2796,2|2022-01-
17T20:45:40Z,53.548523,0.141172,2,30.0625,2|2022-01-
17T20:46:00Z,53.547919,0.143132,2,30.0368,2|
…
18T13:07:20Z,55.474905,8.346988,2,28.3699,2
</om:result>
</om:Observation>
```


The response to the SOS URL contains the whole information needed to interpret the data as well as the data itself in <om:result>.

Using the SOS web service BSH transfers the Hereon FerryBox data to CMEMS and EMODnet.

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8. PLATFORM 4: UNDERWATER GLIDER

- How to use this Handbook:

The Handbook is intended for a wide and diverse audience. It allows quick and easy access to the most appropriate sections. All readers are encouraged to read this introduction and the table below will help you decide which sections are likely to be most relevant to you.

Audience	*Recommended sections*
Glider Operational managers, M&O staff, Glider technicians, Coastal Ocean Observing System managers	8.2, 8.3 Platform Description
Glider Operational managers, M&O staff, Glider technicians, manufacturers	8.4 Sensor(s) and integration into the platform
Marine Data Managers, Glider data users, trainers, students	8.5 Data and Data Management Methods for data collection from platforms

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8.1. Introduction

In the last decade, the need for ocean monitoring has significantly increased, making it necessary to maintain and expand the monitoring capabilities for better understanding the ocean state, variability and changes, and the impact on the marine ecosystem, particularly in the context of climate change. Specifically, the Ocean underwater gliders (hereafter also simply "gliders") have a significant role in addressing societal issues and economic applications, especially in the areas that connect the open basin with the coastal environment [Davis, et al. 2002; Testor, et al. 2010; Rudnick, 2016]. The understanding of ocean boundaries will help us to study the impact of human activities in coastal areas.

The glider's ability to monitor the ocean variability at different temporal and spatial scales allowed sampling the ocean at scales of km and hours. By maintaining endurance gliders you are able to monitor areas over long periods [Lee and Rudnick, 2018]. They can also resolve physical and biogeochemical processes that range from extreme events to climate signals [Glenn, et al, 2008; Todd, et al, 2011; Zaba and Rudnick, 2016; Rudnick, et al, 2017]. In addition, they are capable of sampling across string lateral gradients (e.g., boundary currents and eddies), capturing small-scale and episodic processes (e.g., phytoplankton blooms and carbon export events), and quantifying climate variability.

8.2. Platform overview

8.2.1. Purpose

Gliders are small autonomous underwater vehicles (AUV) that can migrate vertically by changing their buoyancy and steer horizontally by gliding on wings [Stommel, 1989; Eriksen, et al, 2001; Sherman, et al, 2001]. They can be deployed at sea with various physical and biogeochemical sensors that allow sustained observations at high spatial and temporal resolutions. Since gliders require little human assistance while travelling, these normally small size AUVs are uniquely suited for safely collecting data in local and remote locations at a relatively low cost. They allow sampling the ocean and collecting data where it is impractical for human access, such as in the middle of a hurricane or under sea ice. While many glider designs use different techniques to balance and drive through the water, most of the gliders share the ability to travel far distances over long periods without the need for maintenance.

Glider observations provide a better understanding of ocean state and variability, complementing satellites, research vessels, in-situ observations from moorings, buoys. Navies and research organizations use a wide variety of glider designs and sensors for their research.

8.2.2. Description

Ocean Undersea Gliders are autonomous vehicles that can operate for long periods of time underwater. They can collect a large variety of physical and biogeochemical data at high temporal and spatial resolutions. The main Essential Ocean Variables (EOV) from the gliders are temperature, conductivity (converted to salinity), pressure (converted to depth), depth average current, oxygen, chlorophyll fluorescence and backscatter. Depending on the platform and the needs, other low-energy sensors can be added depending on the scientific needs.

Gliders navigate autonomously by using their buoyancy to ascend and descend the water columns between the surface and the maximum depth depending on how they have been programmed to perform. Their wings allow them to move forward along a programmed trajectory. Therefore, data generated by these platforms consist of sawtooth-like vertical profiles at various locations in a specific region. The measured variables depend on the payload sensors installed in the glider before each deployment. Moreover, these measurements may vary along with the mission because their sensor configuration can be changed remotely using iridium communication (Figure 8.1). This periodic remote communication also allows obtaining quasi-real-time data each time the glider surfaces. A subset of the measured data can be sent, considering the transmission of the satellite cost, surface time, and energy consumption (Figure 8.2). Additionally, the complete data set can be downloaded and collected after the glider is recovered in the laboratory. The remote configuration provides a way to appropriately navigate the glider and optimize energy consumption by modifying the sampling frequency and switching sensors where necessary. These changes could have an impact on the output data.

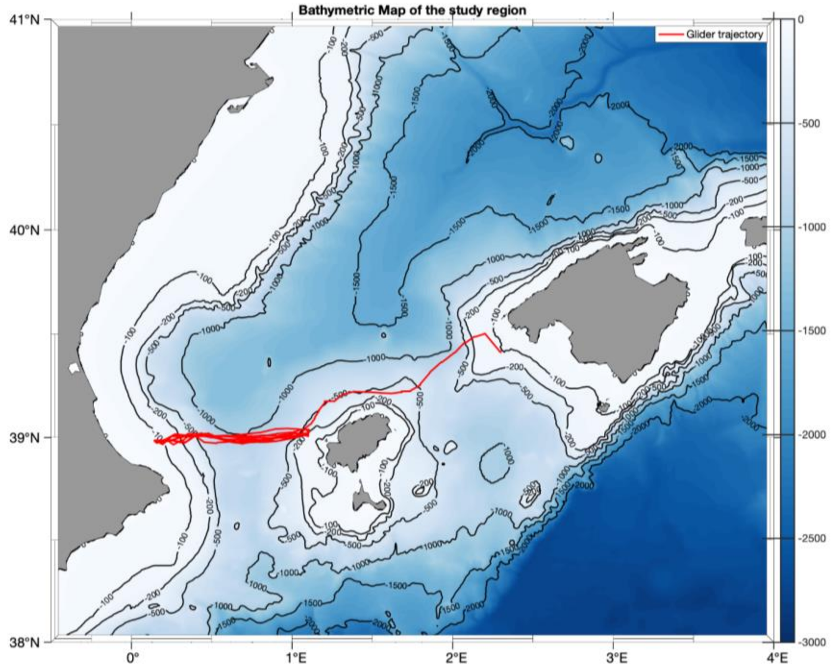

Figure 8.1: A glider trajectory is plotted with red over the bathymetry.

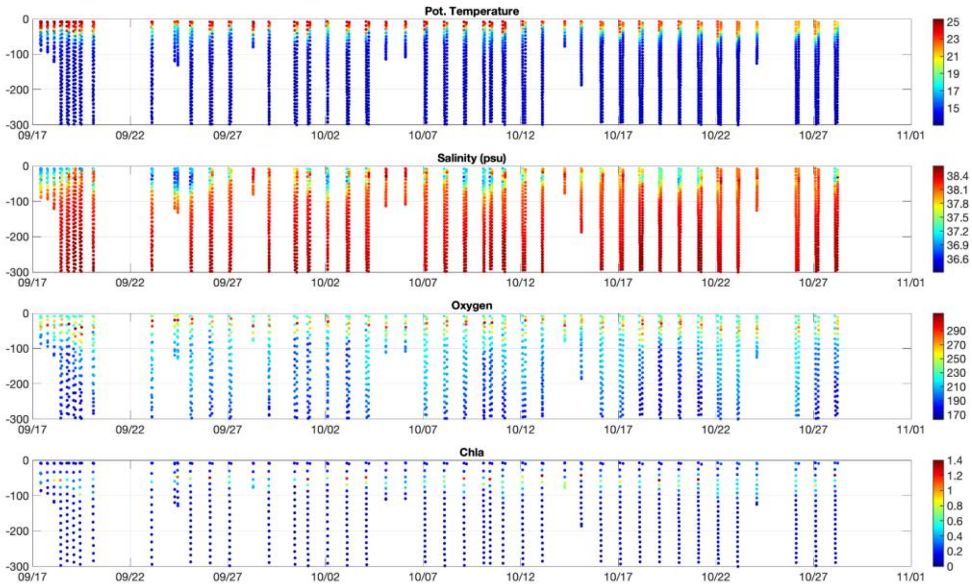

Figure 8.2: Real time plot of temperature, salinity, oxygen and chlorophyll fluoresce during the mission

The most commonly used glider platforms available nowadays are four: Slocum, SeaExplorer, Spray, and Seaglider (Figure 8.3), although there are other types. Gliders are flexible to host a variety of physical and biogeochemical sensors that may provide a diversity of variables. They use different methods to balance and steer throughout the water column. The vehicle pitch is controllable by movable internal ballast (usually battery packs). However, the steering and buoyancy methods differ between the Slocum gliders and the other types of vehicles. Slocum steering is accomplished with a rudder while other gliders steer by moving internal ballast to control roll. Concerning buoyancy, Slocums shallow gliders (up to 200m) use a piston to flood or evacuate a compartment with seawater.

In contrast, SeaExplorer, Spray, Slocum deep gliders (up to 1000m) and Seaglider move oil in/out from an external bladder. In all cases, because buoyancy adjustments are relatively small, the glider's ballast must typically be adjusted before the start of the mission to achieve an overall vehicle density close to the density of the water where the glider will be deployed. Each of them produces different format types of raw data. Moreover, the raw data also contains engineering variables that are used to operate, control and navigate the glider and to support delayed mode quality control. Engineering data depends too on the type of platform, adding complexity to the description of raw glider data.

SeaExplorer glider: https://www.alseamar-alcen.com/products/underwater-glider/seaexplorer


Slocum glider: Photo by Ben Allsup, Teledyne Webb Research


Spray glider: https://www.whoi.edu/what-we-do/explore/underwater-vehicles/auvs/spray-glider/

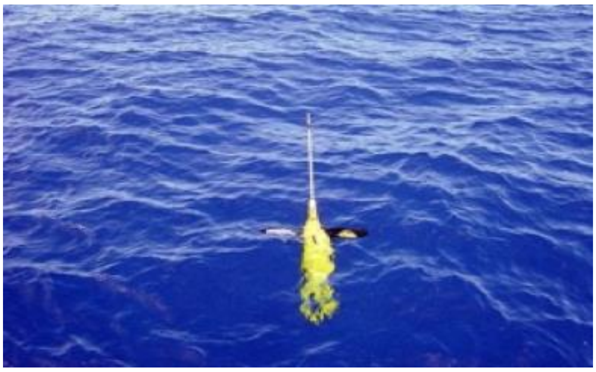
Seaglider glider: https://apl.uw.edu/project/project.php?id=seaglider

Figure 8.3: Major types of gliders

In summary, the complexity of the glider data originates from:

- Diversity of physical and biogeochemical sensors
- Diversity of data for glider formats
- Remote glider and sensor configuration during mission
- Diversity of data: real time, recovery and delayed mode
- Coexistence of the different science and engineering parameters

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8.3. Detailed platform design

8.3.1. Design and functionality of platform

Gliders can be used to explore and observe the ocean by employing the hydrodynamic forces generated by their wings to travel through water columns with only a minor change in buoyancy and altitude. Several types of autonomous underwater gliders have been developed and effectively used in oceanography research in the last decade.Their physical characteristics are similar by having a cylindrical hull, horizontal wings, and tail. Details about the physical characteristics, the setting up of the based station where the glider can communication with the glider pilot, operational glider principles, piloting parameters, pre-deployment and pre-launch procedures can be found in the manufacturers operational manuals as they have been summarized in the **Table 8.1.**

Table 8.1:: Summarizes the main glider manufacturers operational manuals.

Manufacturer manual	URL
Seaglider™ User's Guide	https://www.pacioos.hawaii.edu/wp-content/uploads/2016/08/iRobot_Seaglider_User_Guide-Rev.C-Jan12.pdf
Slocum G2 and G3 Glider Operators Manual	https://gliderfs2.coas.oregonstate.edu/gliderweb/docs/slocum_manuals/Slocum_G2_Glider_Operators_Manual.pdf http://gliderfs.coas.oregonstate.edu/gliderweb/docs/slocum_manuals/Slocum_G3_Operator_Manual_20171219.pdf
SeaExplorer	Under request in ALSEAMAR

Some for the desirable configuration characteristics for gliders include:

- Their ability to carry a variety of physical and biogeochemical sensors. Most commonly equipped with a suite of sensors that can collect Temperature, Conductivity, Pressure, Chlorophyll fluorescence, Oxygen, CDOM, PAR, backscatter at 700 nm and turbidity at high spatial resolutions.
- The capacity of the gliders to communicate in near real-time via iridium satellite communication at every surface is one of its most important features [Testor, et al, 2010; Ruiz, et al, 2012]
- Ability to adjust the sampling strategy and the navigation based on your scientific needs. Every parameter, such as trajectory or sample ratio, can be adjusted while the glider is surfacing (typically every 3-12 hours) to adapt the glider to changing sea conditions and respond to scientific or operational needs.
- Additionally, a portion of the dataset can be sent in real-time throughout the surface time. Glider observations in real-time are already helping with ocean numerical

modelling and forecasting. Physical and biogeochemical measurements in areas of high socio economic relevance can greatly improve regional and coastal models.

Gliders navigate with the help of periodic surface GPS fixes, pressure sensors, altimeter, tilt sensors, and magnetic compasses. The gliders ability to dive from weeks to months contingent on the type of batteries (alkaline, lithium, or rechargeable), mission configuration, and sensor payload, following a programmed trajectory allows scientists to observe the same area repeatedly or to monitor a specific physical process, such as a (sub-) mesoscale eddy providing data at temporal and spatial scales unattainable by powered AUVs and less costly sampling using traditional shipboard techniques [Davis, et al. 2002].
Gliders typically collect measurements such as conductivity-temperature-depth (CTD; conductivity to calculate salinity), currents, oxygen concentration, chlorophyll fluorescence, optical backscatter, nutrients, micro turbulence, bottom depth, and sometimes acoustic backscatter or ambient sound. There is also the possibility of mounting new commercial and custom sensors that enhance their potential and promising future.
During the preparation of glider missions several protocols need to be followed for a successful mission. During this stage, the engineer and scientific team will work closely to design and examine the visibility of the glider mission. The steps are include the following:

1. **Experiment.** Define the sampling strategy and set up the experiment within the timeline required.
2. **Team Communication.** Setting up the communications channels between the team members. Including the announcement of the next glider deployment between the different divisions, by involving the relevant people and the aim of the project.
3. **Hardware Check**
    a. **Check sensors calibration.** Aside from the glider's preparation as a vehicle, calibrating the scientific sensors on board is an equally important phase in the process of preparing a glider for a scientific mission. The sensors must be properly maintained in order to produce high-quality datasets.
    b. **Communications Check.** Gliders typically employ satellite communication to communicate with a base station computer on land [Yahnker, et al, 2012]. Iridium satellite communication has been commonly used from the gliders now a days. Normally, the glider platform's inbuilt Iridium modem is used to establish a satellite connection. In addition to the two-way Iridium satellite communication solution, Slocum and Spray gliders employ the one-way Argos satellite communication system to send brief messages (usually 32 bytes) at 90-second intervals when at the surface. The Argos satellites may or may not take up these communications. If the message is picked up, it can be accessed via an internet service provided by CLS with a one-hour delay (Collecte Localisation Satellites).These messages provide the most recent GPS data available at the time of transmission. Furthermore, using a triangulation approach, the glider's position at the moment of transmission may be calculated with precision up to 1 km if the message is detected by at least three satellites. The Argos system has been installed on the Slocum and Spray gliders for further safety.
    c. **Battery Check.** It is important to closely monitoring the energy of the glider battery and energy consumption of each glider sensor. It is important to define

how much data (density of points) will be communicated in real-time using a near real-time technique or glider data reduction. It is critical to have a high density throughout the first part of the mission to avoid missing any issues. Rechargeable (secondary) lithium-ion batteries with energy densities (at room temperature) approaching 0.7 MJ/kg and primary lithium batteries with up to 2 MJ/kg power today's operations [Davis & Sherman, 2017].

d. **Ballasting**. Ballasting a glider is adding or subtracting weight to match the density of the water where it will be deployed. The salty water is denser than freshwater, and the cold water is denser than warm water. The glider will have difficulty diving if not enough weight is added. On the other hand, If we add too much weight, the glider will dive, but it will struggle to resurface. Neutral buoyancy is essential for flight due to the nature of the buoyancy engine, and it is also significant for energy consumption issues. For example, when ballasting a Slocum glider, the glider must correct for neutral buoyancy, a zero pitch angle, a zero roll angle, and an adequate h-moment arm [Baird, 2007]. Ballasting for neutral buoyancy is a major problem. The volumetric capacity of the buoyancy engine will not be able to enable the glider to alternate between being negatively and positively buoyant if the glider is not precisely ballasted to be neutrally buoyant. If the glider cannot become both negatively and positively buoyant due to the piston's movement alone, it will not be able to glide.

e. **Lab Sensors Tests** of the most common used sensors:
   i. CTD (More information about the Pre deployment protocol can be found in OceanGlider Salinity SOP).
   ii. Oxygen (More information regarding the Pre-deployment operations and calibrations can be find in OceanGlider Oxygen SOP
   iii. For chlorophyll a fluorescence and backscatter sensors perform dark counts test
   iv. Sensor comparison in the water tank

4. Final Sealing. When we double-check that everything within the glider is in working order and that the parts are correctly sealed.

5. Pressure Test: A pressure chamber can help identify leaks in the glider or sensor assembly. The pressure chamber, if it is big enough, can hold the entire glider. Until now only a few facilities have the ability to check the whole glider platform for a potential leak

6. Mission configuration file:

a. Software Configuration
b. Satellite communication. Setting up when the glider will be surface and the target points
c. Data transmission
   i. A subset of the glider data (from 10 to 6000 sec)
   ii. All the profiles regarding the navigation.
   iii. On science profile that could include both upcast and downcasts
d. sampling strategy for physical and biogeochemical sensor
e. Example of sampling priority (regarding energy consumption)
   i. CTD sensor
   ii. Oxygen sensor
   iii. Optical sensors
   iv. PAR (Photosynthetically active radiation from 400 to 700 nm)

7. CEM: Compass Error Measurement and Calibration. Prior to deployment, the vehicle compass needed to be calibrated such that heading and pitch measurements are precise to +/-1.2 degrees. Compass inaccuracies are usually caused by either an incorrect calibration file being installed or a change in the vehicle's hard or soft iron signature occurring after the calibration [in Seaglider Quality Control Manual, 2016] you can find information regarding the quality of compass).Both of these issues can be resolved by changing the calibration file during deployment, which should be annotated using a manual directive. [Merckelbach, et al, 2008] established a method for assessing glider compass inaccuracy in Slocum gliders on land.
8. Equipment transportation between the glider lab to the harbour or boat.
9. Notifying the local authorities.

The increase in glider observations highlights the necessity to create, improve and share best practices regarding glider operation, data collection, and analysis to achieve high-quality in-situ observations [Pearlman, et al, 2019].

8.3.2. Maintenance

A glider lab is essential for the maintenance of the glider. It should be equipped with the necessary work surface and electronic and mechanical glider repair tools. Gliders and glider equipment can be transported easily in a well-designed laboratory Report on best practice in conducting operations and maintaining [Petihakis, et al, 2012]. Furthermore, because testing satellite communication and location systems prior to deployment is typical practice, the laboratory should have easy access to an open space with an unobstructed sky view. A glider laboratory should have a crane to make moving gliders between regions easier and a network connection (LAN or WLAN). In addition, following local health and safety laws, the laboratory should be labelled with exit routes and emergency plans.
Annual planning is highly recommended to provide the necessary time for the facility to get supplies, get prepared, and avoid tight schedules regarding glider operations. The annual plan should include the glider availability, the number of planned missions based on the monitoring observations programmes and projects, the infrastructure maintenance needs, and the personnel availability (Figure 8.4). Glider maintenance and system upgrades are demanding and necessary work for performing successful glider missions. Different glider manufactures have recommended time frames for the maintenance of the equipment. Although the necessity of the engineering team of keeping the glider fleet running is mandatory, the frequency of the glider maintenance varies from the type, use, and age of the glider. The maintenance can include either mechanical parts such as pumps, fins, replacement of o-rings, air bladders, or software updates and sensor configuration. One demanding and meticulous job is the replacement of glider primary batteries and glider maintenance after each mission, which depends on the platform type.
In addition to the glider's preparation as a vehicle, the calibration of the scientific sensors on board is a critical phase in preparing a glider for a scientific mission. The sensors must be properly maintained in order to produce high-quality datasets. The majority of users rely on the manufacturers to calibrate their sensors. It is essential to keep track of the sensors that are coming back from the manufacturer. This is due to professional calibration facilities' expensive setup and operating costs. According to the Report on best practice in conducting operations and maintaining, [Petihakis, et al, 2012] the majority of the sensors are calibrated every 12 months. However, in one instance when the sensors are calibrated prior to each

cruise (by those who have in-house calibration capabilities), this number can be as high as two years and as low as three months. Scheduling ahead for the maintenance of the glider fleet and sensors is essential for the sustainability of the glider operations as it might require months, taking into account the shipping time of spares and customs paperwork.

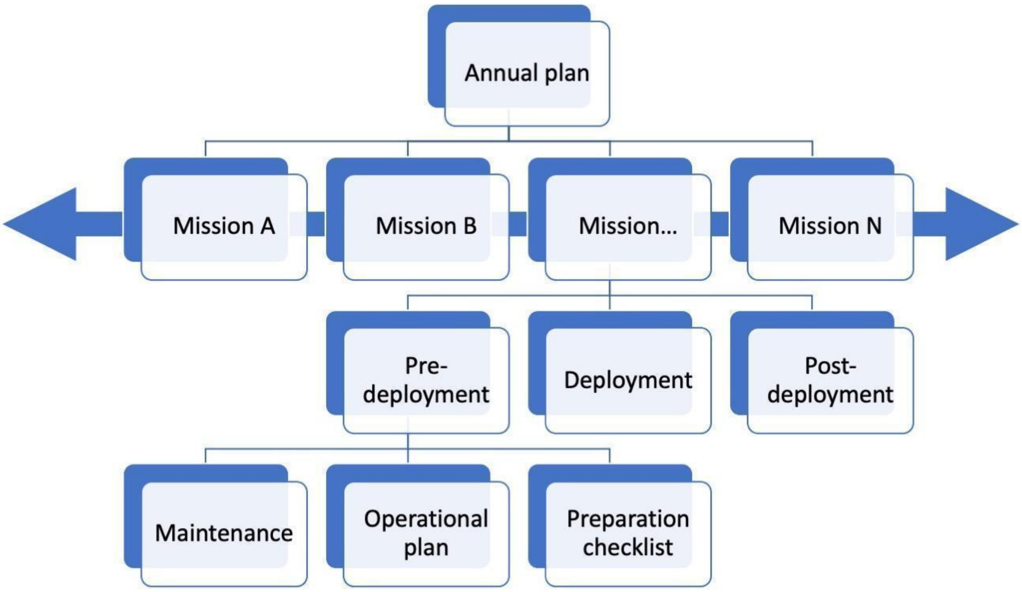

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Figure 8.4: Schematic of the glider operations steps during the year.

8.3.3. Deployment and recovery

Depending on the nature of glider operations, their missions could be in coastal or open waters. Their mission duration can last from days to months and depends on several factors that affect the energy consumption (e.g., sensor payload, sampling frequency, navigation in very dynamic ocean features, and operating in a harsh environment). The glider deployment and recovery can differ as it depends on the glider platform and vessel of deployment/recovery. During the deployment phase, the engineer, scientific, and data managing team evaluates the glider's performance, data quality, and data flow during the mission. A checklist has been developed following the next steps:

- Check of the hardware and software operating the glider platform
- Launching point (it depends on the research vessel, weather conditions, ship traffic and fishing activity (e.g ghost nets, fishing nets and trawl fishing areas).
- Web Page visualization. Check if the glider sampled data appear correctly in the digital platforms
- Check the metadata (Mission name, Mission start (UTC), Mission end (UTC), Short description of the glider deployment)
- Check if the engineer and science files have been created (the files could have different format and also could have different products at different levels L0, L1, and L2)
- Check range of the values for each sensor/variable

Preparation of the glider recovery should be made during the planning of the mission, taking into account all the possible scenarios to avoid potential safety risks of the glider (e.g., mission completions, weather conditions, emergency recovery). During the deployment, if the weather conditions do not permit an immediate emergency recovery, if it is necessary, it will be better not to launch the glider. The recovery of the glider can occur after the mission has been completed as planned. However, an emergency recovery might be necessary if we face a failure in a sensor, hardware issues with the glider's performance, or limitation of the energy consumption.

8.3.4. Analyses of platform performance

The employment of gliders for monitoring areas that connect the open basin to the coastal environment has increased in the recent decade [Davis, et al, 2002; Testor, et al, 2010; Rudnick, 2016]. Gliders play an important role in addressing societal challenges and economic applications, hence developing Key Performance Indicators (KPIs) to assess the worldwide glider network is essential. Some of the KPIs can be accessed via the data management system and encompass features such as planning, real-time data delivery, delayed mode data delivery, and variables as applied by Copernicus-In-Situ-TAC. Copernicus-In-Situ-TAC.

- The amount of deployments scheduled each year could be used as a planning KPI. A network design by the OceanGliders Steering Team (OGST) based on scientific criteria should be a clear goal.
- The percentage of registered deployments that send RT data and the amount of hours between data collection and data transmission to the GDAC could be used as real-time KPIs. It is acknowledged that the RT QC should be carried out and harmonized, but details must be agreed upon.
- As far as Delayed-mode is concerned, The amount of months between data collection and transmission to GDAC, as well as the proportion of registered deployments that submit DM data, could be used as KPIs.
- As a KPI for Variables: A special KPI should be used to track gliders' unique ability to carry many sensors. The number of days at sea and each parameter for the physical and biogeochemical sensors.

8.3.5. Uncertainties in observations

Environmental uncertainties, vehicle design uncertainties, and sensor measurement errors can all be seen in the gliders, and they can all affect the gliders' dynamical behaviour or measurement accuracy. Unexpected uncertainties in the marine environment, such as currents, can cause a significant deviation from the intended course or a severe distortion in the planned mission, resulting in the loss of local communication within the vehicle network. The glider's hydrodynamics and manoeuvrability may be affected by manufacturing and assembly issues (see "Issues" paragraph in Glider Section for details). Sensor measurement errors directly influence the range and accuracy of glider observations. Numerous uncertainties affect the quality of data collected by gliders throughout generating marine data, from the field to the laboratory. The data produced from the gliders are used for scientific research and to inform policymakers and in various other fields, including marine forecasting, so it is essential to identify these uncertainties and establish an effective quality management system. For example, the Depth Average Current (DAC) is accurate within 1 cm s-1 [Eriksen, et al, 2001; Merckelbach, et al, 2008]). Acknowledging that in a region with high tide activity it will be necessary to decide if the tidal constituents could create uncertainties in the estimation of the geostrophic current.

8.3.6. Issues

An ocean glider, like all underwater vehicles, is vulnerable to damage from collisions with surface ships, extreme weather (communication failure), and entanglement while gliding on the ocean surface (Risk and Reliability for the Deep and Ultra Deep underwater gliders [Brito, 2019]. For glider missions that have to be performed in areas with high ship or fishing activity the probability of detection is also much greater at the surface where all the glider stealth attributes are compromised during the surface period.

A glider platform can have software or/and hardware issues that these can be grouped into the following categories:

Faults in the Power System: The most important parameter in gliders is battery problems, because any malfunctioning causes all systems to shut down. As a result, all battery systems are constantly monitored autonomously for short circuits, voltage changes, and component voltages.

Faults in the Leak Detection System: Underwater gliders can work at depths of up to 6000 metres. As a result, proper sealing and watertight systems are required for these vehicles. With the loss of the vehicle, faults in the leak detection system cannot be resolved. While the vehicle is in operation, this system protects itself from drowning by surfacing if there is a leak.

Faults in the Diving System: The glider is controlled by two types of diving mechanisms. The most important is the bladder system, which can change the vehicle's reserve buoyancy by changing the fluid inside the capsule on the vehicle's aft side. When the water inside the capsule is replaced with a lighter fluid, such as oil, which is kept inside the reservoir, the buoyancy of the capsule increases. The second type is a ballast system, which uses pumps to take and discharge water. Leaks in the capsule obstruct the diving system and make it impossible to change buoyancy, resulting in the vehicle's drowning. Buoyancy pumps that are not working properly prevent the glider's centre of gravity from shifting, which affects control.

Faults in the Environmental Detection System: Underwater gliders can be equipped with a variety of sensors that collect physical, chemical, and biological information. Every underwater glider, on the other hand, is equipped with a CTD (Conductivity Temperature and Depth) sensor that can measure changes in salinity and temperature as a function of depth. The mission will be aborted if these sensors malfunction, as they will be unable to collect the required data.

Collision Avoidance System Faults: Underwater glider collisions can be divided into two categories: collision with the seafloor and collision with floating objects. Being trapped in fishnets can also be considered as an underwater glider system colliding. To avoid collision, underwater gliders use a sonar modem, sonar transponders, and an altimeter. With collision, any malfunction of these systems can be resolved.

Faults in Computer Systems: Underwater gliders use three different computer systems. The first is for storing the information gathered. The mission is rendered useless if there are computer malfunctions. The second is for planning and navigation. The second one is in charge of system monitoring and coordination. These computer failures put the mission in jeopardy and can lead to system failure.

Stability and propulsion System flaws: Underwater gliders do not have propellers; instead, propulsion is provided by wings and fixed fins. The glider's moving mechanism is affected if these parts fail or rupture. As a result, the glider will be unable to move in the horizontal plane, making correction of the diving angle impossible.
Failure of the pitch and roll motion correctors lead to unstable diving and wrong navigation. These faults lead to the failure of the mission.

Also other general drawbacks for ocean gliders is their slow movement and their limitation to dive only to 1000m. In addition they do not have the ability to collect samples and only collect physical and biogeochemical observations.

8.3.7. Glider - Platform best practices and standards

- Best Practices

The best practices can be applied to the sensor itself or to the platform. The table below summarizes the available best practices for the gliders. Annual planning is highly recommended to provide the necessary time for the facility to refurbish the gliders, get supplies, get prepared and avoid tight schedules regarding glider operations.

Table 8-2: Glider - Platform best practices

Best Practice /title	refer in Annex 1	Notes
D4.2 JERICO-RI Report on Calibration Best Practices: D4.2. (Version 1.3 - 27/06/14)	*12*	
D5.15 Guidelines for the delayed mode scientific correction of glider data. WP 5 , Task 5.7, D5.15. Version 4.1.	*21*	
Report on best practice in conducting operations and maintaining. D4.4	*23*	
Protocols and Procedures for OOI Data Products: QA, QC, Calibration, Physical Samples. Version 1.22., Consortium for Ocean Leadership, 2013	*30*	
Recommendations for in-situ data Near Real Time Quality Control. [Version 1.2].	*31*	
OceanGliders Oxygen SOP v1.0.0	*29*	

Ocean Gliders delayed mode QA/QC best practice manual Version 3.0	*28*	
D5.5 Uncertainty estimation for temperature, salinity & chlorophyll-a.	*25*	
D4.3 Report on Biofouling Prevention Methods.	*24*	
D5.11 Best practices for quality control of sensor based biochemical data. Version 1.3. .	*18*	
OceanGliders Salinity SOP	*39*	*Under review from the scientific community*
OceanGliders Nitrate SOP	*40*	*Under review from the scientific community*
OceanGliders Depth Average Currents (DACs) SOP	*41*	*In preparation*

8.4. Gliders - Sensors and integration into platform

8.4.1. General description

Gliders typically carry a suite of sensors that can collect conductivity, temperature, pressure, currents, oxygen concentration, chlorophyll fluorescence, optical backscatter, PAR, bottom depth, and sometimes acoustic backscatter or ambient sound. Nowadays the glider payload is expanding and now there is also the possibility of mounting new commercial and custom sensors that enhance their potential. However, the integration of a new sensor should be done under careful consideration as it could have a significant impact on the energy budget and hydrodynamic flight characteristics of the glider.

Flight efficiency is determined not only by the qualities of the vehicle, but also by how it is flown. Returning to the fundamental notion of particular energy consumption in equation (see eq. 6.6 in the Underwater Glider System Study), it is clear that boosting the lift to drag ratio, L/D, reduces flight energy consumption. Combining the suitable vehicle features as mentioned above with the selection of the glide path angle b at which the glider is flown maximizes the L/D. A unique relationship exists between the greatest L/D obtained and the angle of the glide path (Figure 8.5), (see Figure 4.2 in the Underwater Glider System Study [Jenkins, et al, 2003] by the proportionality between the force and speed triangles. Path stability and turning performance are dependent on vertical and horizontal stability. Dynamic stability in both horizontal and vertical planes is required for a highly manoeuvrable glider [Javaid, et al, 2017]. A stable glider with no control input may exhibit straight-line stability in the horizontal plane, but hydrostatic restoring forces and moments are likely to destabilize the glider in the vertical plane. A moving internal mass determines a glider's stability. External fixed wings and a vertical rudder can also be used to adjust a glider's dynamic stability.

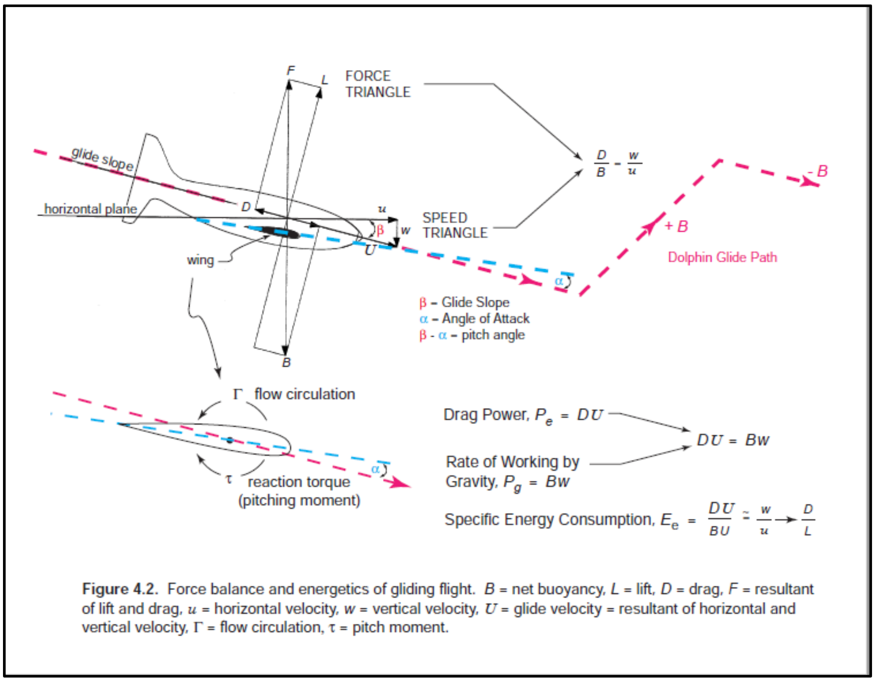

Figure 8.5: Force balance and energetics of gliding flight. B = net buoyancy, L = lift, D = drag, F = Resultant of lift and drag, u = horizontal velocity, w = vertical velocity, U = glide velocity = resultant of horizontal and vertical velocity, G = flow circulation, t = pitch moment.

- Brief description of sensors

Ocean gliders represent a technological revolution because they require very little human assistance and therefore are suited to safely collecting data in local and remote locations at a relatively low cost. Additionally, they allow sampling of the ocean where it is impractical for human access, such as in the middle of a hurricane or under sea ice. Due to these attractive properties, a large diversity of scientific sensors has been developed during the past decades [Testor, et al, 2019]. Gliders provide engineering information that informs of the status of the glider and the trajectory, as well as some basic physical information such as pressure, temperature, and currents. It is not easy to make a comprehensive list of the available sensors that have been used and installed in gliders. Different glider platforms (Slocum, Seagliders, Spray, and SeaExplorer) provide a high diversity on the available sensors carried out with their specific features for each sensor.

From a general perspective, glider manufacturers focused initially on measuring essential physical variables such as pressure, temperature, and salinity. These sensors have been improved over the years and are very reliable. Other physical variables were incorporated and elaborated over time as currents and turbulence [Cauchy, et al, 2018]. Due to the price and ability of gliders to reach remote locations, manufacturers developed a full range of sensors to perform biogeochemical measurements relative to the marine ecosystem's biogeochemical processes. In particular, sensors sensor have been developed to measure chlorophyll fluorescence, turbidity, backscatter at different wavelengths (most common 460, 532, 650, and 880 nm), dissolved oxygen, CDOM, irradiance, nitrate, and recently acoustic sensors (acoustic backscatter or ambient sound) that have become popular for fisheries and marine biodiversity research. There is also the possibility of mounting and integrating new commercial and custom sensors that enhance their potential and promising future. The glider community has developed a set of Standard Operating Procedures (SOP) for the most mature sensors in the framework of the OceanGliders programme. These SOPs contain a more detailed list of the commonly used sensors based on the measured variable (see section 8.5.6).

8.4.2. Detailed description

Ocean gliders can collect a wide range of measurements and typically have multiple sensor suites on board for each mission. In this document we will focus on the following physical and biogeochemical sensors that are widely used: CTD, Oxygen, FL3, PAR/OCR and ADCP.

- CTD sensor

The CTD sensor measures conductivity, temperature and pressure. Currently, three types of CTD sensors are used on gliders with the CT sensors can be unpumped or pumped. More details regarding the different types of CTDs in the ocean gliders, sensor integration, pre-deployment protocols, mission execution, field calibrations, storage and etc can be found in the OceanGlider Salinity SOP https://oceangliderscommunity.github.io/Salinity_SOP/README.html

- Oxygen sensor

Measurements of ocean oxygen content, one of the most fundamental variables in chemical oceanography, have recently returned. This is hardly unexpected, considering the importance of oxygen in determining the state of the marine carbon cycle and monitoring the biological pump's pulse. The sensors of choice for autonomous observations are oxygen optodes, commonly used on biogeochemical-Argo floats, gliders, and other platforms [Johnson, et al, 2017; Nicholson & Feen, 2017). However, data quality and accuracy are often poor because sensor and data processing is not always easy, and/or sensor characteristics are not effectively considered. Gliders primarily use oxygen optode sensors to measure the oxygen concentration and saturation in the water column [Sea-Bird Electronics, Inc, 2013]. Oxygen optodes work based on oxygen quenching luminescence. [Kautsky, 1939] gave one of the first descriptions, and molecular oxygen quenches practically all luminophores [Lakowicz, 2006, chap. 8]. The oxygen optode sensors are based on the ability of selected substances to act as dynamic fluorescence quenchers and are used to measure absolute oxygen concentration and percent saturation [Bittig, et al, 2018]. A particular platinum porphyrin complex is embedded in a gas permeable foil exposed to the surrounding water as the fluorescent indicator. More information about the different types of oxygen sensor that have been used in the ocean gliders, sensor integration, pre-deployment protocols, mission execution, field calibrations, storage and etc can be found in the OceanGlider Oxygen SOP

- FL3

Optical backscatter of particulates at various wavelengths for measuring fluorescence of phytoplankton pigments (e.g., chlorophyll a, phycocyanin), colored dissolved organic matter (CDOM) and optical backscatter. Various environmental (e.g. temperature) and platform dependent (e.g. power) parameters can affect dark counts in bio-optical instruments [Cetinic, et al, 2009].

- PAR/OCR

Gliders are commonly equipped with a Photosynthetically Active Radiation (PAR). The sensor is used to measure the spectral range of light that is available in the water column for use by primary producers for photosynthesis (400-700 nanometers), and how that varies over time and depth in the water column. More information for the biospherical PAR sensor can be found here.
Multispectral radiometers are fully digital sensors that combine precision optics and high performance microelectronics to provide spectral records of light collected in an ocean environment. OCRs are designed for applications in which performance, size, and power are key constraints. These sensors can be mounted on profilers, moorings or AUVs. OCRs sensors are designed to measure radiance or irradiance in water at 4 to 7 wavelengths. Measurements allow estimating, among other parameters, the diffuse attenuation coefficient (Kd) and the penetration depth [Xing, et al, 2020]; useful for ocean colour validation from satellites.

- ADCP

ADCPs are commonly used on moorings and vessels to monitor currents, acoustic backscatter. Few years ago, integration was done on gliders (Gentil et al., 2022) in order to better estimate sediment transport on continental shelves. Nortek AD2CP were successfully integrated on Seagliders and Seaexplorer to investigate water motions on continental shelves [Rollo, et al, 2020; de Fommervault, et al, 2019] and RDI DVL were implemented on slocum glider [Gentil, et al, 2020].

ADCPs are commonly used on moorings and vessels to monitor currents and acoustic backscatter. In recent years, several groups have worked to integrate ADCP into gliders and various commercial solutions are now available:

- Slocum with a Teledyne RD Instruments [Ordonez, et al, 2012]
- Sontek sensor on Spray [Davis, 2010; Todd ,et al, 2011]
- Nortek AD2CP mounted on Seagliders (Jonker, et al, 2019), SeaExplorer (de Fommervault, et al, 2019) and Spray (Todd, et al, 2016).

While using ADCPs on gliders is challenging, their use has proven to be effective in addressing key scientific issues such as underwater positioning [Russello, 2013; Tanaka, et al, 2022], water column dynamics / sediment transports [Todd, et al. 2011; Gentil, et al, 2022; Davis, et al, 2008] and acoustic plumes detections [de Fommervault, et al, 2022). Recent developments are now focusing on near-real time processing on board gliders [Todd, et al, 2016] which will enable their use to be extended and complementary to other surface measurements. The near-real time use of combined HF Radar and glider-ADCP observations allow us to observe a detailed view of coastal water motions [Masson, 2021].

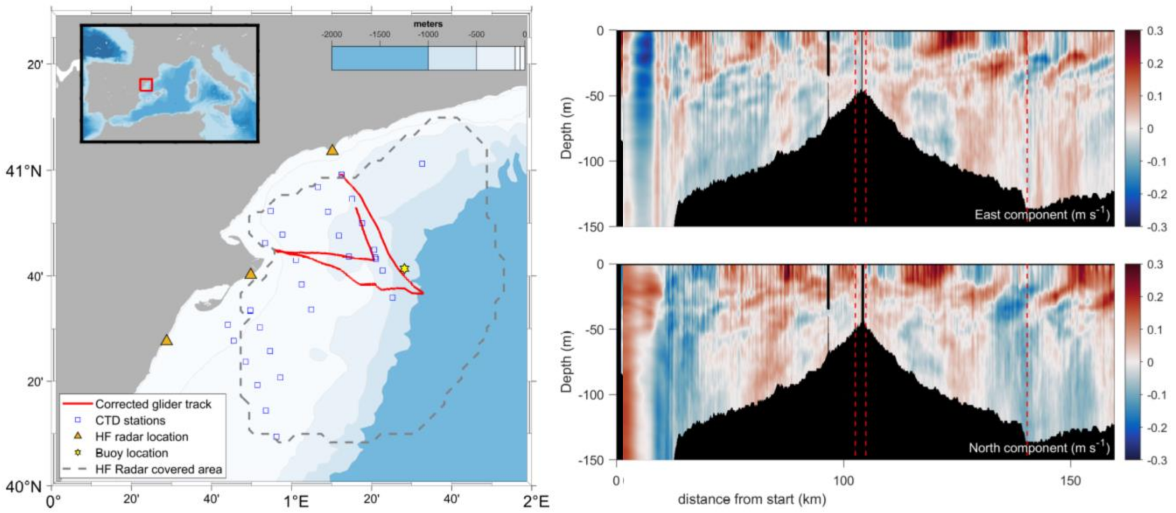

Figure 8.6: Left panel, map of the Ebro delta area with glider track in red. Right panel: Near-real time of glider-ADCP data.

8.4.3. Sensor calibration

Annual planning for the factory calibration is highly recommended; this will provide the necessary time for the operators to maintain the sensors in a given payload, get the sensor prepared, and avoid tight schedules regarding the calibration of the sensors and glider missions. Commonly, most glider sensors require annual factory calibration. The sensor calibration frequency also depends on the biological activity of the region or the period. The annual plan should include an evaluation of the glider sensors, considering the number of planned missions, sensor calibrations costs, and personnel availability. The calibration record for each glider sensor is needed on a given glider mission. It is also necessary data to be included in the mission metadata. Calibration and maintenance activity associated with each sensor used on a given glider mission should be documented and included in the mission metadata. The calibration of each sensor should follow the manufacturer's recommendation or be performed earlier if needed after evaluating the observations. In addition, in situ sensor validation (e.g., CTD casts, water sampling with Niskin casts) should be performed during both glider launch and recovery, as equipment, vessel, and weather allow as it will help to provide high-quality observations.

8.4.4. Uncertainties in observations

Occasionally, there may be more than one subtly different flavour of stable mixing line during a single glider mission, which can last up to 2 months or more; this is identified by having more than one solution from the three initial guesses as mentioned above. Much of the time, the resulting uncertainty is within the 0.003 level that the manufacturer would set as limiting anyway and we can select any one of the solutions. However, it can indicate that the glider dataset needs to be split before inter- calibration, either due to a change in instrument characteristics, or, rarely, that a genuine subtle change in mixing line has occurred during a glider mission.

8.4.5. Quality Assurance methods

The use of ocean gliders has resulted in an increase in the amount of data available, between the open sea and coastal water. The automatic quality assurance/quality control (QA/QC) required to guarantee that the data obtained is fit for purpose has become increasingly vital as real-time intake of glider observations has become increasingly important for forecasting systems. Current automated QA/QC systems provide assessments based on hard classifications of the collected data; frequently as a binary judgement of good, probably good or bad data, which fails to quantify our confidence in the data for usage in various applications [Timms, et al, 2011]. Uncertainty in measurement requires the inclusion of a quantitative indication of the quality of the measurement result along with the result itself, so that others who utilize the measured data can assess its reliability. Standard uncertainty is normally calculated using scientific judgement based on all available data, which may include: a) historical observations in the study area, b) knowledge of the sensor behaviour and sensor accuracy, 3) manufacturer's specifications and in-situ data that provided for the calibration of the glider sensors.

8.4.6. Issues

Ocean glider CTD and oxygen optode sensors primarily face sensor response problems [Bittig, and Körtzinger, 2017; Garau, et al, 2011]. It happens because sensors do not change their output immediately for a sudden change in input. Rather, sensors change their output to the new state over a period of time, called the response time. On the other hand, gliders' optical sensors face primarily offset and dark count issues. Another vulnerability is the maintenance of the sensors including their calibrations due to shiptime, manpower or funding. Furthermore, biofouling could affect the sensor behaviour and the quality of the observations.

8.4.7. Gliders - Sensor best practices and standards

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• Best Practices

Table 8-3: Gliders - Sensor best practices

Best Practice /title	refer in Annex I	Notes
Report on best practice in conducting operations and maintaining: D 4.4. (Version 1 - 27/02/2012). DOI:10.13155/49741 [Petihakis, et al, 2012]	23	

Different scientists and engineers from various institutes and universities have developed several 'best practices' regarding the physical and biogeochemical sensors that gliders carry out. These 'best practices,' however, are not all in one place; many are scattered across multiple papers, handbooks, guides, training materials, project reports, and institute protocols. The research and operations communities are addressing this through the creation and use of the Ocean Best Practices System [www.oceanbestpractices.org]. Recently, the scientific community has made a significant effort to develop a set of community-accepted best practices for the various physical and biogeochemical parameters collected by glider sensors. In addition, best practices are available regarding glider operations and data

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management (Report on best practice in conducting operations and maintaining,[Petihakis, et al, 2012].

8.5. Gliders - Data and data management methods

8.5.1. Description of data

There are various approaches leading to processed data from glider observations. One good practice that considers the heterogeneous nature of the glider data is to parse the raw data and create three levels (L0, L1, and L2) of standard NetCDF files (see Figure 8.6). The L0 level contains both scientific and engineering parameters sent from the glider. The L1 level files contain observations, calibrations, unit corrections, and derived variables such as salinity. It also includes delayed mode corrections like the thermal lag (Garau et al., 2011) or salinity cross-calibration [Allen, et al, 2020]. The L2 level files are gridded observations from the glider profiles. This profile-like data can be helpful for modelling applications and comparing the information with Argo profile data. Historically, the format of these files is homogeneous within each institution. However, substantial efforts have been made to harmonize the format at the international level. The Everyone's Gliding Observatories (EGO) defined the EGO glider NetCDF standard [Carval, et al, 2022], aiming to harmonize the L1 data. Later, the OceanGliders (OG) programme created the OG1.0 format to support interoperability within international standards in the USA, Australia, and Europe. This standard aims to support FAIR principles and to strengthen the network community.

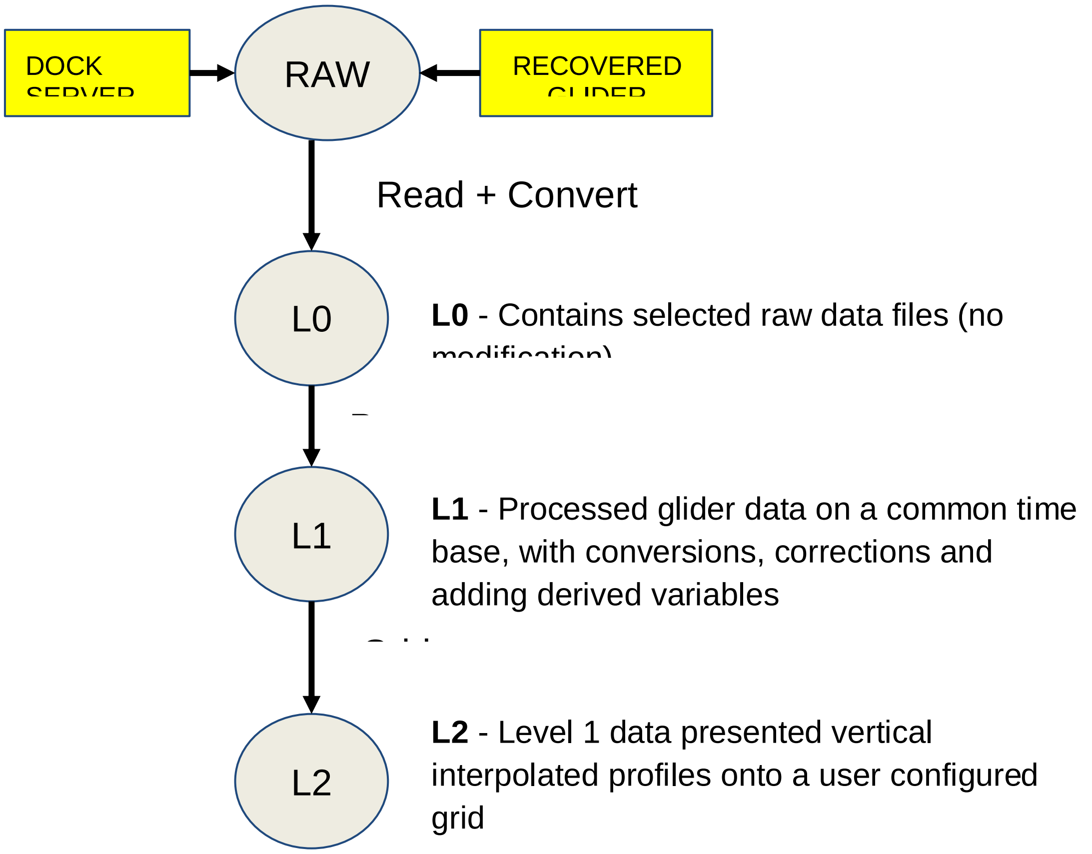

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Figure 8.7: Processing levels of glider data

In general, glider data management must align with the OG principles and the best practices and adopt their recommendations and formats to ensure interoperability with the international community and the long-term durability of JERICO glider data.

8.5.2. Data value chain: from acquisition to delivery

Gliders are long-endurance autonomous vehicles that move through the water column along a predefined path to respond to a specific scientific goal. Data collection procedures start at the deployment preparation stage when making the observational and operational plan. The data collection flow includes the following steps:

- Planning
- Deployment
- Data transmission
- Data processing
- Data archiving
- Data dissemination and visualization
- Data distribution

The EuroGOOS Glider Task Team (https://eurogoos.eu/gliders-task-team/) defined the standard data flow of glider data, ensuring in particular their dissemination and long-term persistence. Usually, the glider operators define the planning of a glider mission, the deployment of the glider, and the different phases of the transmission of the glider observations. Data processing, archiving, dissemination and visualization is performed by the Data Assembly Centers (DAC), which plays an essential role in the dissemination process through the Global Data Assembly Center (GDAC). Some organizations have the capabilities to operate gliders and assemble the data as a DAC. Otherwise, a network of DAC is available to allow the data flow to the GDAC. Coriolis is the European GDAC, and it ensures that the glider data flow is in the required format for the international infrastructures, such as GTS for use in Numerical Weather Prediction and ocean forecasting. DAC must guarantee that the data is provided in the standard format: EGO or OG for international interoperability with other GDAC. Coriolis guarantees that the data flows to the European data aggregators such as Seadatanet, CMEMS Instac, and EMODnet. Figure 8.8 is the specific case of the Data Management Plan (DMP) of SOCIB as an example of the possible flow of glider data. SOCIB is an organization that operates gliders and acts as a DAC for glider data, including external organizations internationally. Glider users should comply with the OG Data management plan for a more general data flow.

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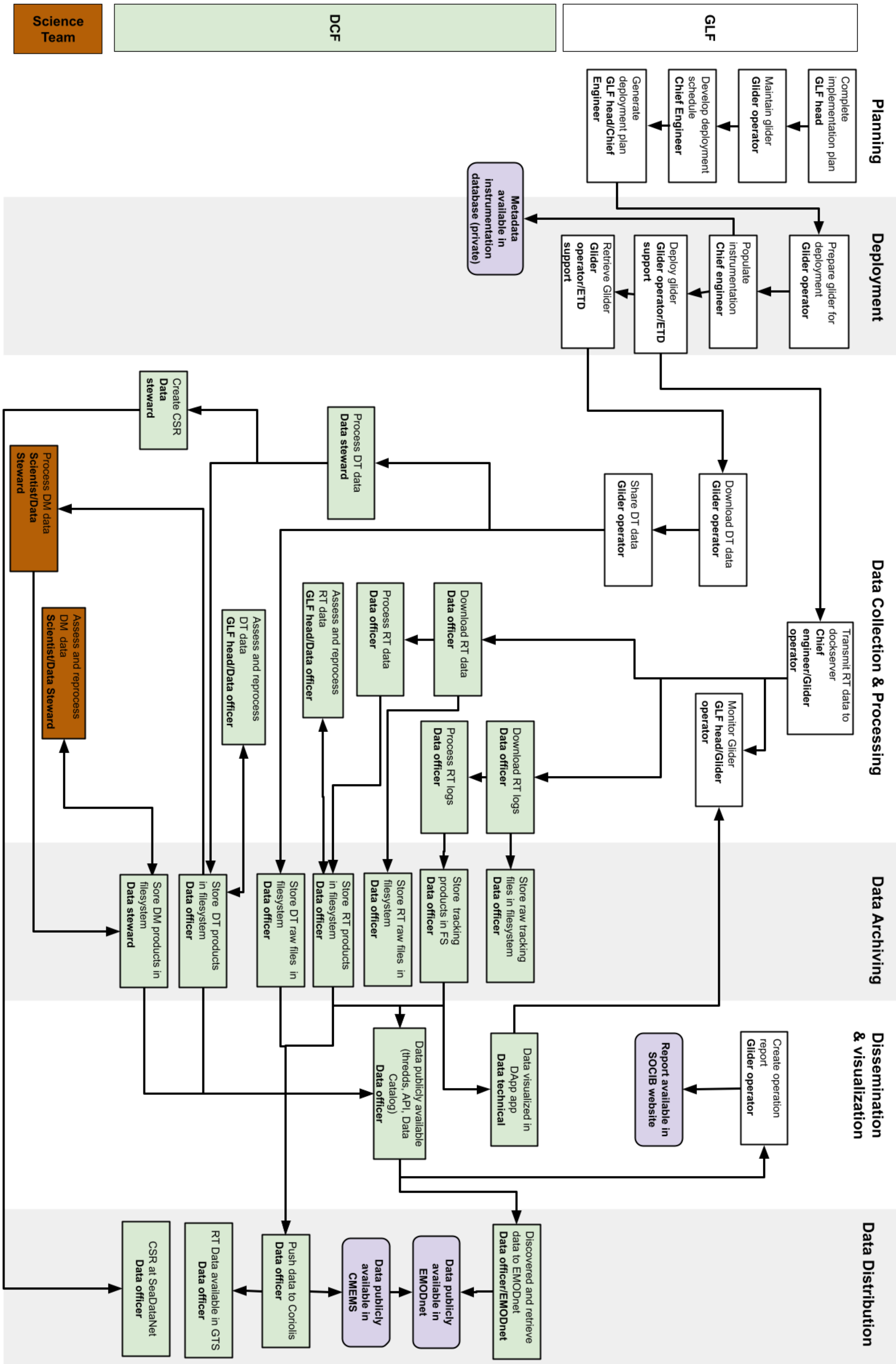

Figure 8.8: SOCIB Data Management Plan [Maresco, et al, 2021] as an example of data flow from operation to data collection and distribution from DAC to GDAC and Aggregators.

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We have to differentiate between near-real-time (NRT), recovery, and delay mode data in the data flow, as Figure 8.9 indicates. Real-time data is transmitted via satellite to the glider operator server. Basic QC is applied to this data by GDAC or possibly (but not mandatorily) by DAC. DAC needs to promptly provide real-time data to GDAC to be used by GTS in the forecast models. Real-time data is only a subset of the total amount of measured data. The complete set of data is collected after the recovery of the glider. Similar to real-time, recovery data may contain QC, and they are provided to DAC/GDAC soon after collection. Delayed mode data is usually produced with human intervention. It contains corrected data such as thermal lag, salinity correction, or data interpolation. Additionally, it must contain the QC of each of the variables. Various versions of the dataset can be provided to GDAC at different times as the correction process evolves.

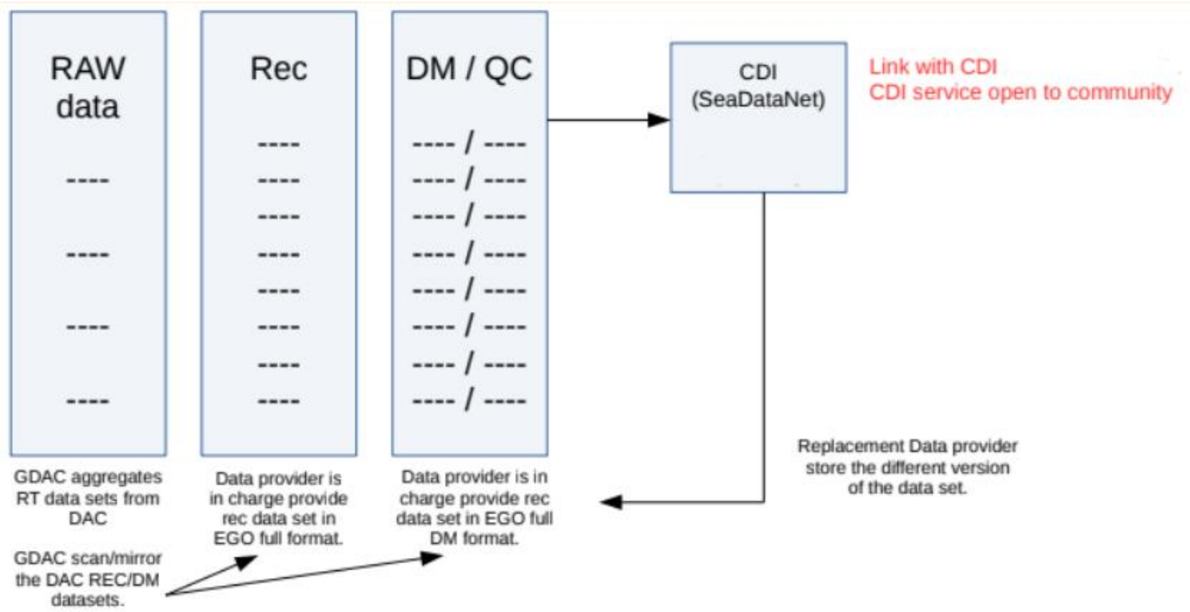

Figure 8.9: Data distribution strategies for real time, recovery data and delayed mode glider data.

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- Metadata information and data format

As mentioned earlier, due to the diversity of sensors and platforms, metadata and formats of raw data from gliders are heterogeneous. Furthermore, the metadata for each glider is complex because it includes scientific, engineering and sometimes custom variables of the manufacturer. As an example, John Kerfoot at Rutgers University published the list of Slocum metadata [Kerfoot].

OceanGliders aims to harmonize the L1 level products for real-time, recovery, and delayed mode data. It works toward global interoperability between standards of different continents in order to reach FAIR principles adopted by the Global Ocean Observing System (GOOS). The data model is compliant with the Climate and Forecast Metadata Convention CF-1.8 specifications. Data is recorded as a trajectory discrete geometry where each data file contains a series of profiles that represent the entire mission of the glider. The format follows the Attribute Conventions for Data Discovery (ACDD) 1.3 convention. The vocabulary collections are hosted in different places (i.e., NERC Vocabulary Server -NVS, OceanOPS, and ICES) as shown in Figure 8.10.

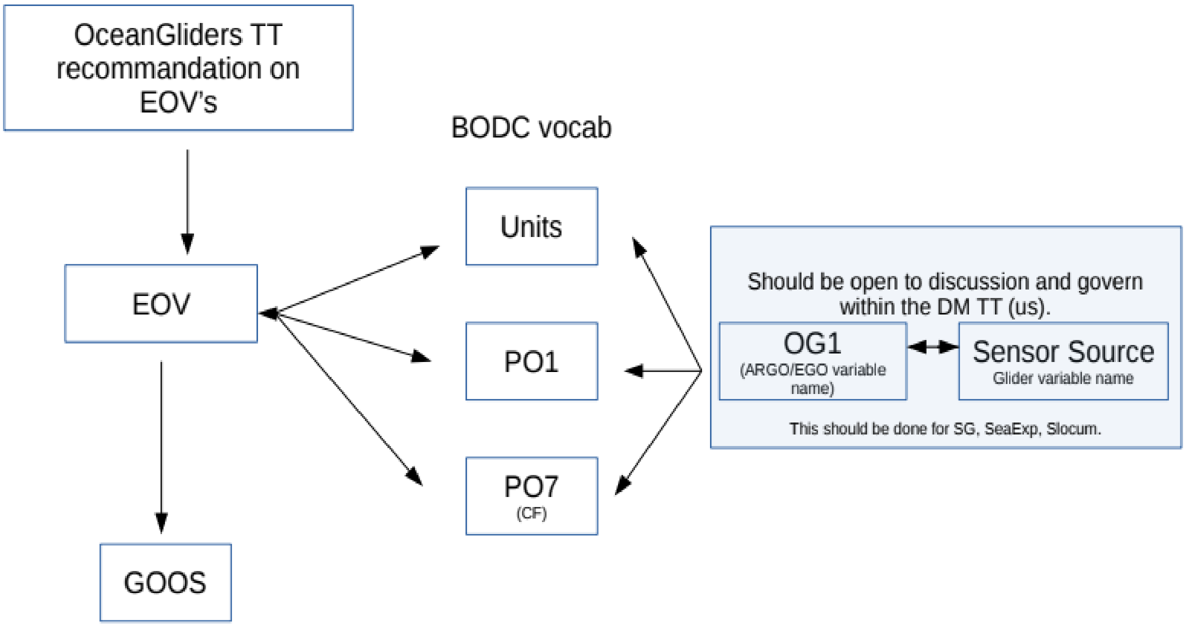

Figure 8.10: Vocabulary conventions used for glider data as decided by the EuroGOOS Glider Task Team in 2019.

The conventions adopted by OceanGliders (OG) are described in detail at the [OG format user manual (https://github.com/OceanGlidersCommunity/OG-format-user-manual/blob/main/OG_Format.adoc)](https://github.com/OceanGlidersCommunity/OG-format-user-manual/blob/main/OG_Format.adoc) This document includes the description of the global attributes, the variable names and conventions, vocabularies, coordinate and time standards, variable attributes, and dimension definitions. This convention uses British Oceanographic Data Centre (BODC) vocabularies as well as SeaDatanet metadata services, including European Directory of Marine Organization (EDMO), European Directory of the Initial Ocean-Observing Systems (EDIOS), European Directory of Marine Environmental Research Projects (EDMERP), and Common Data Index (CDI). It also promotes the use of standard identifiers such as the Research Organization Registry (ROR) and the International Council for the Exploration of the Sea (ICES). Despite the use of controlled vocabularies and global identifiers, an effort has to be made related to identifying other resources in the JERICO catalogue. For example, datasets should ideally include the JERICO identifier of the software or service-producing them as well as the identifiers of the Best Practices used along with the data flow. It is also recommended that ORCID identifiers are used to identify related actors.

-
- Data policy

Glider data flows to the European aggregators via Coriolis (https://www.coriolis.eu.org/Data-Products/Data-Delivery). The access to the data in this portal follows the data policy of these infrastructures. They comply with the open-access distribution of data. At the data provider level, it is also recommended to adopt a free distribution approach using Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/).

-
- Data dissemination – Link to European/International Data Banks

Several data providers may distribute glider data, but the European marine portals play an essential role, as stated by OG. The distribution in Europe of glider data to the EMODnet and CMEMS Instac is performed via Coriolis as agreed by the community with the support of the Eurogoos Glider Task Team during the international meeting in Genoa, Italy in 2018 (see Figure 8.11). Additionally, it is recommended that the data is also registered in SeaDataNet using CSR. Thus, physical data from glider will be available in the main European marine data portals CMEMS-INSTAC (http://www.marineinsitu.eu/), EMODnet Physics (https://map.emodnet-physics.eu/) and SeaDataNet (https://www.seadatanet.org/). It will also be available globally for ocean forecasting and weather predictions in the WMO information system because Coriolis provides the data to GTS in the required format.

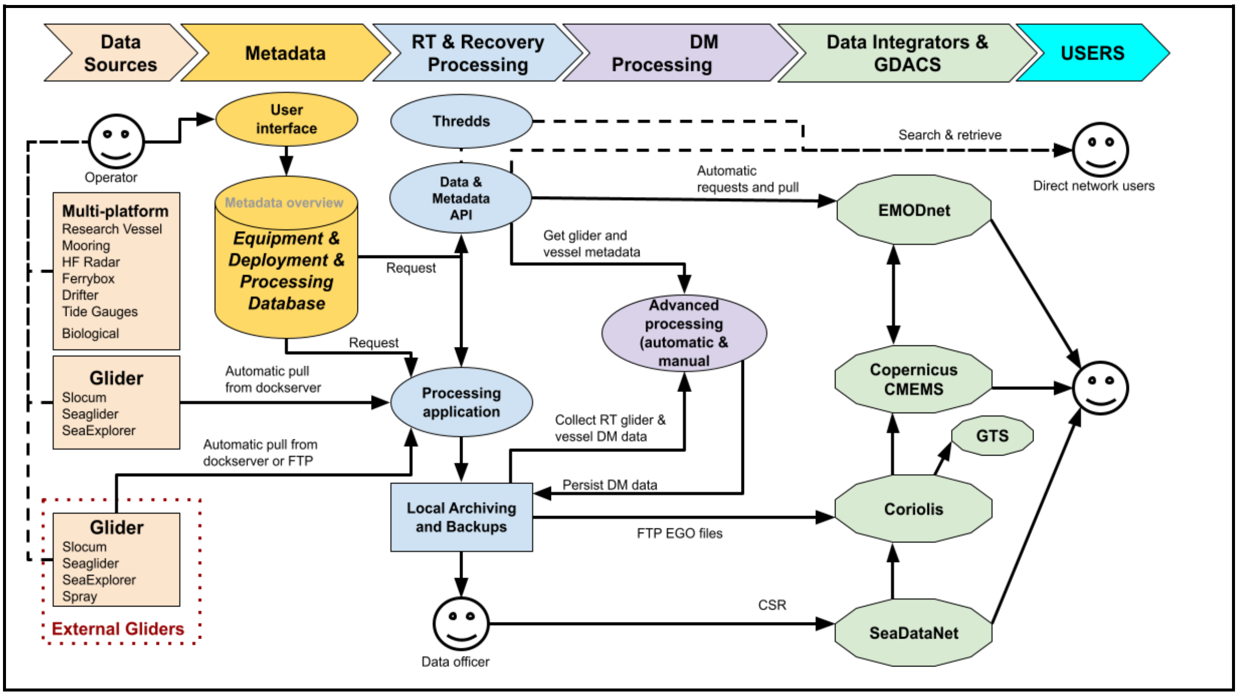

Figure 8.11: Example of glider data flow for a multi-platform system with operational and DAC capabilities.

In order to improve the access to and persistence of the data, DAC should provide a DOI for the different levels of the dataset. Ideally, a DOI should be included in the metadata of the dataset. Optionally, the same DOI may be used for all levels of the dataset. Each level may be identified by adding a suffix that identifies the data level and version (see Figure 8.12)

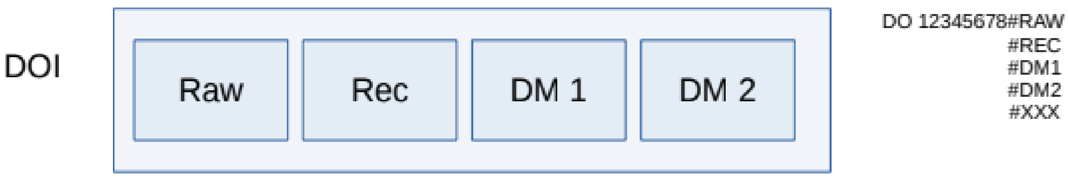

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Figure 8.12: DOI strategy for glider data set up by the EuroGOOS Glider Task Team.

●

8.5.3. Quality Control and Quality Assurance

Quality control and assurance (QC/QA) has an essential role in the life cycle of glider observations. In recent years the glider community has started to develop the necessary protocols and standards for harmonizing and defining the different levels of data quality. QC in the glider observations, we refer to the application of methods and procedures that determine whether the observations meet the overall quality international standards and defined quality criteria for individual parameters. The QA, on the other hand, defines the various processes that research institutes seek to ensure that the glider observations maintain the international standard or have improved.
DAC or GDAC applies quality control procedures in an automated mode to facilitate real-time data QC in the latest phases by identifying some of the problems. These automated flags also support the ability to filter data that have been sent to GTS. Problems that are not detected by these automated procedures should be detected in the delayed mode QC with the interaction of a human expert. This section provides details about the QC/QA processes in real-time and delayed mode.

- QC/QA Overview of Near-Real Time and recovery data

In contrast to delayed mode QC, what defines a QC technique as 'real time' or 'near real time' for gliders is that both scientists and engineers may have a subset of all the information on land during the glider deployment due to satellite bandwidth. The data availability depends on the cost of the satellite communication, surface time, and operation risks. In real-time, we should always expect limited and incomplete data. However, the decimate observations should offer us enough information regarding data quality on a horizontal and vertical scale. The particular issue of real-time QC is to evaluate the most recent data point. Based on the data nature, we have defined the role of real-time QC data:

1) Real time data is acquired typically seconds to hours and can be instantly used for model ingestion. This is often the case for operational modeling communities that require data within 24 hours, requiring automated procedures, and are aware that the data has not been subjected to climate grade QC. They require data that has undergone a rough QC to ensure that data assimilations are not harmed. However, the outcomes of real time QC are used to inform later stages of QC, such as when data tagged 3 (possibly poor) is evaluated, it is changed to 4 (bad data) based on the flagging scheme that the user applied.
2) The real time data can be a useful source for manager decisions and policy makers.
3) To ensure that high quality glider observations gather and detect failure with the on-board sensors

Although the majority of the automatic checks are often connected with real-time QC, and while they do better meet the needs and requirements for the real-time data stream, they should not be confined to them. The close monitoring of the real-time observations by pilots and scientists at least once a day or every couple of days is one of the main features of the real-time QC. Based on the nature of the real-time QC, we could distinguish the following levels:

a) Checks for quick response are performed automatically.
b) Automatic update once more information becomes available to better support an evaluation, referred to as near real-time (like more vertical profiles available, deeper profiles to stable waters, comparison with other platforms available in the study area, changes on the instrument configurations, etc)
c) Manual assessment is highly recommended. Pilots and PIs keep a tight watch on the real time observations in the hopes of spotting something suspicious in the data.

Basic automatic QC tests can be applied to any geophysical parameter. Similar automatic QC tests have also been developed for biogeochemical observation. The **Table 8.2** summarizes a series of QC tests that are automatically run to flag geophysical variables.

Table 8.4: Basic QC tests applied automatically to data

QC method name	Transfer parameters	Description
NaN Check	Any variable	Flag NaN values as 9
Impossible date check	Time	Tests that time values are within the timeframe associated with the deployment and mark bad entries as 4
Impossible location check	Longitude, Latitude	Tests for impossible values (-90<=x<=90 and -180<=y<=180), and that the values are sensible for this deployment and mark bad entries as 4
Valid range check	Scientific data	Tests if values are within the expected ranges. Four types of range tests should be applied according to these aspects: ● Sensor ranges ● Global ranges ● Regional and local ranges Mark entries that fail the test with the specific flag.
Spike test	Scientific data (only T and S?)	Identifies spikes based on Argo Data Management (Argo, 2013) test. Mark bad entries as 6.
Gradien test	Scientific data	Test the difference between vertically adjacent measurements. Values that are too steep are flagged as 4.
Surface data test	Optical sensor data	Data from optical sensors are usually noisy at the surface and are flagged as 4.

In both cases, data are not modified, but instead, they are labeled in a separate QC variable with the same parameter name as the suffix _QC. The aim is to identify issues in the data and flag them in a separate variable used to mask the data in the original geophysical

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variables. Several quality flag schemes can be used and adopted in the glider observations. Depending on the flag scheme that the user applies, each flag can have different meanings. However, most of the available flag schemes are focused on the same approach and aim to characterize the observed values in the most precise and accurate way.
In 2013 UNESCO/IOC recommended a flagging standard Table 8.3 [Intergovernmental Oceanographic Commission, 2013] where the QARTOD adopted it in 2014. In recent years many institutions have followed and used the UNESCO/IOC standard as it has been recommended by the glider experts. The adopted QC flagging scheme for glider data is the ARGO QC flag scale (which extends the UNESCO scale, [ARGO].

Table 8.5 UNESCO/IOC flag scheme.

Flag*	Description
Pass=1	Data have passed critical real-time quality control tests and are deemed adequate for use as preliminary data.
Not evaluated=2	Data have not been QC-tested, or the information on quality is not available
Suspect or Of High Interest=3	Data is considered to be either suspect or of high interest to data providers and users. They are flagged suspect to draw further attention to them by operators.
Fail=4	Data are considered to have failed one or more critical real-time QC checks. If they are disseminated at all, it should be readily apparent that they are not of acceptable quality.
Missing data=9	Data is missing; used as a placeholder.

***** UNESCO scale

Even though the most common flag scheme is the UNESCO/IOC flag scheme, high heterogeneity in the flag schemes exists among the community. Table 8.4 shows an example of the mapping between the SEADATANET flag scheme with the other available flag schemes. A mapping between the available schemes has been created to harmonize the different quality flag schemes between the organizations .
(http://seadatanet.maris2.nl/v_bodc_vocab/browse_export.asp?l=L201&all=yes&description=1&x=45&y=15)

Table 8.6: Mapping of the SEADATANET flag scheme.

Flag description	ODV	GTSPP	ARGO	SEADATANET	ESEAS	WOD	QAETOD	BODC	SMHI	OceanSITES	UNESCO/IOC

no quality control (QC) was performed	1	0	0	0	0	0	0	Q	*	0	1
QC was performed; good data	0	1	1	1	1	0	3	*	*	1	3
QC was performed; probably good data	0	2	2	2	1	0	3	*	*	2	4
QC was performed; probably bad data	4	3	3	3	3	4	2	K	?	3	3
QC was performed; bad data	8	4	4	4	4	4	1	K	B	4	4
QC was performed;the value was changed as a result of QC	1	5	5	5	2	0	0	R	|	5	2
QC was performed;the value below detection	1	0	0	6	0	0	0	<	<	0	2
QC was performed; the value in excess	1	0	0	7	2	0	0	>	>	0	2
QC was performed; the value is missing	1	9	9	9	9	0	9	N	B	9	9
QC was performed; the value phenomenon uncertain	1	0	0	A	0	0	0	Q	B	0	2

Valid Range Check for sensors and the global ocean

To define the ranges for each parameter that QC will be applied to, it is necessary to understand the limitations of each instrument on the glider and the study area. There are various ranges based on the type of the sensors and the user's specific requirements. The first ranges to consider are the ones given by the instrument specifications (example of different types of sensors; Values of the measurement must be within the range specified by the manufacturer of the sensor. The calibration datasheet of each of the sensors used in the glider provides the required information to perform the sensor range test.

Table 8.7: Shows the ranges for some sensor manufacturers

Variable	Sensor range	Sensor
Temperature [º C]	-5 to 42	Slocum Glider Payload CTD
Conductivity [S/m]	0 to 9	Slocum Glider Payload CTD
Turbidity [NTU]	0 to 25	Wetlabs
Chla-Flu [mg/m3]	0 to 50	Wetlabs
Oxygen concentration [umol/l]	0 to 500	Aanderaa oxygen optode
Oxygen sat [%]	0 to 120	Aanderaa oxygen optode

In general, some rules can be applied to any sensor manufacturer. For example, chlorophyll, turbidity, oxygen concentration, and oxygen saturation should be positive and below a very high threshold.

Concerning global ranges of the various physical and biogeochemical variables, depth specific thresholds can be adopted from the User Manual of the World Ocean Database 2013. [Johnson, et al, 2013]. However, QC is usually applied independently of the depth. The global values are specified by different sources, as summarized in Table 8.6.

Table 8.8: Global ranges for various physical and biogeochemical variables

Variable	Global range	Source
Temperature [º C]	-2.5 to 40	DATAMEQ, 2010
Salinity [PSU]	2 to 41	DATAMEQ, 2010
Conductivity [S/m]	0 to 8.5	ARGO User manual. V3.2 (2015)
Turbidity [NTU]	0 to 50	GROOM / ARGO qc V2.8, 2013

Chla-Flu [mg/m3]	0 to 50	Argo QC Manual For Biogeochemical Data
Oxygen conc [mmol/l]	0 to 600	ARGO
Oxygen sat [%]	-	-

As we aim to make observations in specific regions, values can fit to specific observational areas. These values should be clearly within the global range, and they allow a more restrictive way to identify bad measurements. These regional values depend on the location of the observation. Each operator and DAC should consider the values defined for their specific area. For example, ARGO/DATAMEQ defined the values for the Mediterranean Sea of the temperature (10 to 40 ºC) and salinity (20 to 40 PSU). SOCIB has been able to reduce these global ranges based on 10 years of monitoring Ibiza and Mallorca channels, as Table 8.7 indicates.

Table 8.9 Local range values around the Balearic Islands in Spain. These values were defined by SOCIB based on 10 years of sustained observations.

Variable	Local ranges in Balearic Islands
Temperature [º C]	10 to 30
Salinity [PSU]	35 to 40
Conductivity [S/m]	4 to 6.5
Density [kg/m3]	990 - 1035
Turbidity [NTU]	0 to 10
Chla-Flu [mg/m3]	0 to 5
Oxygen conc [mmol/l]	140 to 350
Oxygen sat [%]	50 to 120

Spike Test

A spike in both size and gradient is the difference between sequential measurements when one measurement is notably different from nearby ones. The objective is to run the data via a rolling filter (along the time dimension), which can be used as a starting point. Spikes distinguish the data from the original.

Test value = $| V2 - (V3 + V1)/2 | - | (V3 - V1) / 2 |$

where V2 is the measurement being tested, and V1 and V3 are the values above and below.

For the physical parameters like temperature and salinity, this test ignores the pressure differences. Instead, it assumes a sampling scheme that accurately replicates temperature and salinity changes as a function of pressure. This algorithm applied to vertical temperature and salinity profiles.

- **Temperature**: The V2 value is flagged when the test value exceeds 6.0°C for pressures less than 500 dbar, or the test value exceeds 2.0°C for pressures greater than or equal to 500 dbar.
- **Salinity**: The V2 value is flagged when the test value exceeds 0.9 PSU for pressures less than 500 dbar, or the test value exceeds 0.3 PSU for pressures greater than or equal to 500 dbar

Gradient Test

This test fails when the difference between vertically adjacent measurements is too significant. The test overlooks pressure variations because it assumes that the changes of variables implicitly contain these variations.

Test value = | V2 − (V3 + V1)/2 | where V2 is the measurement being tested, and V1 and V3 are the values above and below.

For example, temperature and salinity variables are flagged as 4 in the following scenarios

- **Temperature:** The V2 value is flagged when the test value exceeds 9.0°C for pressures less than 500 dbar, or the test value exceeds 3.0°C for pressures greater than or equal to 500 dbar.
- **Salinity**: The V2 value is flagged when the test value exceeds 1.5 PSU for pressures less than 500 dbar, or the test value exceeds 0.5 PSU for pressures greater than or equal to 500 dbar.

Near Real Time visualization

The Table 8.8 summarizes a list of plots that are highly recommended to perform to ensure QA on the main observed physical and biogeochemical parameters during the glider deployment. These plots help to detect spikes, outliers, and sensor issues.

Table 8.10: List of plots during the glider deployment to ensure QA in the observations

Scientific parameters	Frequency
Map of the glider trajectory with the last profile indicated	Daily
Time series plot per sensor • CTD (Temperature, Conductivity and Salinity) • Optical sensor/s (CHL fluorescence, Turbidity, Backscatter and CDOM) • Oxygen sensor (Oxygen concentration, Oxygen Saturation and Temperature)	Daily

Time series vs depth plot per sensor color code ● CTD (Temperature, Conductivity and Salinity) ● Optical sensor/s (CHL fluorescence, Turbidity, Backscatter and CDOM) ● Oxygen sensor (Oxygen concentration, Oxygen Saturation and Temperature)	Daily
Vertical profiles for the whole depth range and for the first 200m ● Depth vs Temperature, Conductivity and Salinity ● Depth vs CHL fluorescence, Turbidity, Backscatter and CDOM ● Depth vs Oxygen concentration, Oxygen Saturation and Temperature	Daily
All profiles superimposed the last profile for the whole depth range ● Depth vs Temperature, Conductivity and Salinity ● Depth vs CHL fluorescence, Turbidity, Backscatter and CDOM ● Depth vs Oxygen concentration, Oxygen Saturation and Temperature	Daily
TS plots ● All profiles superimposed the last profile ● All profiles superimposed the last profile for the deep waters	Every few days
TS color code with CHL fluorescence, Turbidity, Backscatter,CDOM and Oxygen	Daily
Temperature (from oxygen sensor) vs Oxygen color code with depth	Daily
Comparison between sensors ● Pressure of CTD vs navigation pressure of the glider ● Oxygen temperature vs temperature of the CTD vs fluorometer	Daily
Intercomparison with other available platforms in the region (Ship-based observation and Argo floats).	Daily
TS diagram between downcasting and upcasting for detecting issues with the CTD pump	Every few days

- Delayed Mode QC

For real time data, further delayed mode QC can flag bad values when identified by an experienced user. In addition, delayed mode QC may also modify values by using advanced algorithms. These changes do not occur in the original variable to avoid losing the original information. An additional variable with the _corrected suffix should be created that contains a copy of the variable values. These corrected variables may be modified during the delayed mode QC process. The most common corrections applied to the data are:

- Removing bad profiles
- Data interpolation

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

- Outliers
- Spike correction
- Thermal lag correction
- Salinity correction
- Dark counts
- Quenching correction

A higher level of QC is carried out on the recovery data by the DAC. In the following sections, we explain more details about some of these corrections.

Removing bad profiles

In this step you can remove vertical profiles from bad glider dives taking into account the first STD or the median with the first STD at the reference depth.

Data Interpolation

Data interpolation consists of applying interpolation algorithms to fill NaN values that were identified during the real time process. Linear interpolation is commonly used for time, latitude and longitude.

Outliers (IQR and STD)

Outliers can be removed by using the interquartile range and standard deviations of the whole dataset. Filters can be made more or less severe by adjusting the multipliers. By following the value ranges for each parameter based on past observations, we can define the degree of the adjusting. Most of the time, erroneous measurements are frequently made vertically.

Spikes Correction

By removing spikes in each parameter, we are smoothing the vertical profiles. The data can be filtered using two different rolling filters. A rolling median is the counterpart of the median approach. Data is first subjected to a rolling minimum and then a rolling maximum in the min and max technique. This is especially valuable in optics data because spikes are particles in the water column that are not evenly distributed. The median approach is probably ideal in the case of salinity because "spikes" could be both positive and negative (Gaussian distribution).

Thermal lag Correction

[Pinot, et al, 1997)] established, based on in situ data in the Mediterranean, that the effect of thermal lag in Slocum G1 gliders is considerable in areas with a sharp thermocline. The salinity and the density are strongly biased due to the thermal lag effects on conductivity measurements. In fact, the salinity errors result from the mismatch between temperature (measured outside the conductivity cell) and conductivity (measured inside the conductivity cell). More modern gliders use pumps and minimize the effect of the thermal lag. However, it is critical to correct thermal lag when the pump is not available in the CTD. [Garau, et al, 2011] propose two algorithms to correct this effect. One is based on estimating the conductivity that would be measured outside the cell. The second one infers the temperature inside the conductivity cell.

Salinity Correction

The calibration of salinity from the glider can be performed using the vessel data from missions in the same transects as the glider close to the dates of the same missions. A semi-automatic delay mode correction may be used based on white maximization image analysis [Allen, et al, 2020] to calibrate the salinity against vessel data.

Dark count Correction

The calculation of a dark count in situ is required to compensate for sensor drift from factory calibration. The 95th percentile of bio-optical data between 200 and 400 metres is used to determine the dark count values for the optical parameters.

Quenching correction

Gliders give us the ability to measure chlorophyll fluorescence and help us to better understand the phytoplankton distributions. However, the validity of these datasets can be jeopardized by underestimating the daytime fluorescence derived from different regional and temporal scales. Existing approaches in the literature have adjusted for quenching. However, these methods rely on assumptions that aren't valid in all places or seasons. [Thomalla, et al, 2018] shows that by multiplying a mean nighttime fluorescence to backscattering ratio by daytime backscattering profiles from the surface to the depth of quenching (defined as the depth at which the day fluorescence profile diverges from the mean night profile), we are able to correct daytime quenched fluorescence [Thomalla, et al, 2018]. The approach described here overcomes some of these assumptions, resulting in adjusted surface fluorescence throughout the day that nearly matched profiles from the prior (or subsequent) night, with a difference of less than 10% in the observed chlorophyll fluorescence.

8.5.4. Issues

There is a technical debate regarding the present workflow, which includes the link to Coriolis, which ideally should be readdressed in order to make use of machine to machine tools from data providers, such as Data API and ERDAPP servers.

In addition, the availability of a global database would simplify the process of collecting glider and missions metadata across borders. This database should of course provide the opportunity to link the metadata to datasets in a flexible way so the metadata can be updated afterwards by data operators. This metadata catalogue should account for the fact that the data lives by nature in a distributed landscape. It should also address the fact that the data is duplicated in various formats in the servers of data providers and main European data portals. It will also be beneficial to have an API supporting the access and visibility of the metadata. A global metadata catalogue would also support the processing at a global scale by GDACs by providing a common metadata repository that assimilates the information of the operations comprehensively.

Finally, QC testing at the data provider level is lacking due to the absence of tools to support the process.

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

8.5.5. Training materials

A series of workshops and glider schools were organized by the community along the years. These workshops were intended to strengthen the glider network and standardize procedures and formats. Table 8.9 reports the list of courses and workshops.

Table 8.11: List of workshops related to glider data management

Title	Date	Details and Materials
1st EGO Workshop	2-3 October, 2006	https://www.ego-network.org/dokuwiki/doku.php?id=public:ego_workshops:ego2006
2nd EGO Workshop and Glider School	25-31 October, 2007	https://www.ego-network.org/dokuwiki/doku.php?id=public:ego_workshops:ego2007
3rd EGO Workshop and Glider School	27-31 October, 2008	https://www.ego-network.org/dokuwiki/doku.php?id=public:ego_workshops:ego2008
4th EGO Workshop and Glider School	17-21 November, 2009	https://www.ego-network.org/dokuwiki/doku.php?id=public:ego_workshops:ego2009
5th EGO Workshop and Glider School	14-18 March, 2011	https://www.ego-network.org/dokuwiki/doku.php?id=public:ego_workshops:ego2011
6th EGO meeting & Final Symposium of the COST Action ES0904	16-17 June, 2014	https://www.ego-network.org/dokuwiki/doku.php?id=public:ego_workshops:ego2014
7th EGO Conference	26-29 September, 2016	https://www.ego-network.org/dokuwiki/doku.php?id=public:ego_workshops:ego2016
8th EGO Meeting	20-24 May 2019	https://www.ego-network.org/dokuwiki/doku.php?id=public:ego_workshops:ego2019
Glider School Plocan Website	Since 2011-ongoing/every year	https://gliderschool.eu/previous-edition/

There are a few software packages that are available to support processing, management and quality control of glider observations (see Table 8.10).

Table 8.12: List of materials related to glider data management

Software Package	URL

SOCIB Glider Toolbox [Troupin, et a, 2015]	https://github.com/socib/glider_toolbox
SOCIB salinity correction toolbox [Allen, et al, 2020]	https://github.com/socib/salinity-correction-toolbox
EGO data checker [Copernicus, 2015]	https://www.seanoe.org/data/00344/45538/
CoTeDe is an Open Source Python package to quality control (QC) oceanographic data such as temperature and salinity [Castelão, 2020]	https://github.com/castelao/CoTeDe
Glider tools is a Python 3.6+ package designed to process data from the first level of processing to a science-ready dataset (delayed mode quality control) [Gregor,et al, 2019]	https://zenodo.org/record/4815417#.YebNrVjMLzc

8.5.6. Gliders - Data best practices and standards

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Table 8-13: Gliders **-** Data best practices and standards

Best Practice /title	refer in Annex I	Notes
Guidelines for the delayed mode scientific correction of glider data. WP 5 , Task 5.7, D5.15. Version 4.1. [Allen, et al, 2018]	21	
Delayed Mode QA/QC Best Practice Manual Version 3.0 Ocean Gliders, IMOS. [Woo and Gourcuff, 2021]	28	
Manual for Real-Time Oceanographic Data Quality Control Flags (version 1.2) [U.S. Integrated Ocean Observing System, 2020]	42	
Manual for Quality Control of Temperature and Salinity Data Observations from Gliders, Version 1.0. [U.S. Integrated Ocean Observing System, 2016]	43	
SeaGlider Quality Control Manual Version 1.13 [Seaglider, 2016]	44	
Australian National Facility for Ocean Gliders (ANFOG) Data Management Users Manual Version 3.1 [IMOS, 2012]	45	
Argo quality control manual, Version 2.9 [Argo, 2013]	46	

OOI Data Product Specification for Global Range Test Version 1.01. [OOI, 2012]	47	
Handbook for Data Management activities regarding data flow and data integration, Atlantos D7.4 [Harscoat and Pouliquen, 2016]	48	
Report harmonization in data and data processing to facilitate the interoperability of the systems, Atlantos D7.1. [Koop-Jakobsen, et al, 2016]	49	
SeaDataNet data management protocols for glider data WP9 – Deliverable D9.14. [Hebden and Buck, 2019]	50	
OceanGliders 1.0. Harmonizing format across OceanGliders. Terms of References [OceanGiders, 2021]	51	
In site sensing: Ocean gliders [Zarokanellos et al, 2023]	52	

The standards and conventions are described in the OG data format. These standards and conventions are summarized below:

Standard/Convention	URL
OG1.0 Format	https://github.com/OceanGlidersCommunity/OG-format-user-manual/blob/main/OG_Format.adoc
EGO1.3 Format	https://archimer.ifremer.fr/doc/00239/34980/ https://www.ego-network.org/dokuwiki/lib/exe/fetch.php?media=public:datamanagement:v1.3:guidelines_to_fill_a_json_file_v1.3.1.docx
Climate and Forecast Metadata Convention CF-1.8	http://cfconventions.org/Data/cf-conventions/cf-conventions-1.8/cf-conventions.html#trajectory-data
Unidata NetCDF Attribute Convention for Data Discovery (ACDD)	https://www.unidata.ucar.edu/software/NetCDF-java/v4.6/metadata/DataDiscoveryAttConvention.html
SeaDataNet Metadata Formats	https://www.seadatanet.org/Standards/Metadata-formats
The Ocean Gliders Data Management Task Team (OGDMTT) proposes a new BUFR	https://github.com/wmo-im/BUFR4/issues/16

sequence to report the full suite of glider observations along a trajectory profile, including biogeochemical parameters, on the GTS.	
OG Standard Operating Procedures	https://github.com/OceanGlidersCommunity/DataAssemblyCenter_SOP

The following National Environment Research Council (NERC) vocabularies are recommended:

Vocabulary	URL
P01	https://vocab.nerc.ac.uk/collection/P01/current/
P07	https://vocab.nerc.ac.uk/collection/P07/current/
L06	https://vocab.nerc.ac.uk/collection/L06/current/
L06 platforms	http://vocab.nerc.ac.uk/collection/L06/current/27/
C86	https://vocab.nerc.ac.uk/collection/C86/current/
OG1	https://vocab.nerc.ac.uk/collection/OG1/current/

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9. ANNEXES

○ Annex I: Master table of best practices

ID	Project	Deliverable Nr (if JERICO)	Title	release date or last update	link to document
1	JERICO-NEXT	D2.2, Version 1.2	Report on the status of sensors used for measuring nutrients, biology-related optical properties, variables of the marine carbonate system, and for coastal profiling, within the JERICO network and, more generally, in the European context. Version 1.2	2017-06	https://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-Deliverable-2.2.pdf
2	JERICO-NEXT	D2.4 PART 1, Version 1.0	Report on Best Practice for new network systems-part 1: HF-radar , WP2, Deliverable 2.4. Version 1.0.	2019-05	http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO_NEXT_Deliverable_2.4_final.pdf
3	JERICO-NEXT	D2.4 PART 2, Version 4.3	Report on Best Practice for new network systems-part 2: cabled coastal observatories. WP2, Deliverable 2.4. Version 4.3	2019-07	published as pp.103-141 with Part 1 above http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO_NEXT_Deliverable_2.4_final.pdf
4	JERICO-NEXT	D2.5, Version 1.0	Report on Best Practice in the utilization of sensors used for measuring nutrients, biology related optical properties,variables of the marine carbonate system, and for coastal profiling. Version 1.0	2019-09	http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO_NEXT%20_Deliverable%20_2.5_Version%201.0.pdf

5	JERICO-NEXT	D2.7, Version 2.0	The "JERICO Label", Version 2	2019-09	http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT_Deliverable_2.7_FINAL-Version%201.0.pdf
6	JERICO-FP7	D3.1, Version 1.7	JERICO-RI Report on current status of Ferrybox: D 3.1 (Version 1.7)	2014-02	http://www.jerico-ri.eu/download/filebase/jerico_fp7/deliverables/D3.1%20Ferrybox%20best%20practices%20v1.7.pdf
7	JERICO-NEXT	D3.1 Version 9	Novel methods for automated in situ observations of phytoplankton diversity. WP.3, D3.1,Version 9.	2017-10	http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-Deliverable-3.1_V9.pdf
8	JERICO-NEXT	D3.2 Version 5	Novel methods for automated in situ observations of phytoplankton diversity and productivity: synthesis of exploration, intercomparisons and improvements. JERICO-NEXT WP3, Deliverable 3.2. Version 5.	2019-08	https://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT_Deliverable_3.2_130819_V5.pdf
9	JERICO-NEXT	D3.3, Version 1.0	Report on first methodological improvements on retrieval algorithms and HF radar network design, Deliverable D3.3. Version 1.	2017-09	http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-Deliverable_3.3_v1.0.pdf
10	JERICO-NEXT	D3.4, Version 2.0	Report on final assessment of methodological improvements and testing on infrastructures, Version 2	2019-07	http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT_Deliverable_3.4_180719_final.pdf
11	JERICO-NEXT	D3.9, Version 1.3	Final report on improved carbon system sensors, WP3 Deliverable 3.9, Version 1.3.	2018-08	http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-

					Deliverable_3.9_FINAL.pdf
12	JERICO-FP7	D4.2, Version 1.3	JERICO-RI Report on Calibration Best Practices: D4.2. (Version 1.3 - 27/06/14)	2014-06	https://www.jerico-ri.eu/download/filebase/jerico_fp7/deliverables/D4_2_Report%20on%20Calibration%20best%20practices_v1-3rev.pdf
13	JERICO-NEXT	D5.1, Version 1.3	Recommendations on open and free data policy , Deliverable D5.1, Version 1.3.	2017-08	http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT_Deliverable_5.1_v1.3.pdf
14	JERICO-NEXT	D5.3, Version 1.1	Specifications for a European FerryBox data management system, WP5.3, D5.3. Version 1.1.	2017-09	https://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT_Deliverable_5.3_v1.1.pdf
15	JERICO-NEXT	D5.4, Version 4.0	Marine biological data: quality control and management practices. WP5, D5.4. Version 4.0.	2017-02	https://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-Deliverable-5.4.pdf
16	JERICO-NEXT	D5.5, Version 3	Document describing the biological data Version 3	2019-08	https://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO_NEXT_Deliverable_5.5_final.pdf
17	JERICO-NEXT	D5.9, Version 2.1	Report on data management best practice and Generic Data and Metadata models. V.2.1 [Deliverable 5.9]	2017-07	https://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-Deliverable_5.9_v2.1.pdf
18	JERICO-NEXT	D5.11, Version 1.3	Best practices for quality control of sensor based biochemical data. Version 1.3. [Deliverable 5.11].	2017-11	http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-

					NEXT_Deliverable-5.11_v1.3.pdf
19	JERICO-NEXT	D5.13, Version 1.0	Recommendation Report 1 for HFR data implementation in European infrastructures , JERICO-NEXT WP5–Data Management, D5.13. Version 1.0.	2017-03	http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-Deliverable-5.13_V1.pdf
20	JERICO-NEXT	D5.14, Version 1.0	Recommendation Report 2 on improved common procedures for HFR QC analysis, JERICO-NEXT WP5-Data Management, Deliverable 5.14, Version 1.0.	2018-10	http://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-Deliverable_5.14_V1.pdf
21	JERICO-NEXT	D5.15, Version 4.1	Guidelines for the delayed mode scientific correction of glider data. WP 5 , Task 5.7, D5.15. Version 4.1.	2018-09	https://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-Deliverable_5.15_Final.pdf
22	JERICO-NEXT	D5.16, Version 2.0	Linking JERICO-NEXT activities to a Virtual Access infrastructure, WP5, Deliverable D5.16. Version 2.0.	2017-02	https://www.jerico-ri.eu/download/jerico-next-deliverables/JERICO-NEXT-Deliverable-5.16_V2.pdf
23	JERICO FP7	D4.4, Version 1.0	Report on best practice in conducting operations and maintaining	2012-01	https://www.jerico-ri.eu/previous-project/deliverables/d4-4-report-on-best-practice-in-conducting-operations-and-maintaining/
24	JERICO FP7	D4.3, Version 1.0	Report on Biofouling Prevention Methods	2014-01	https://www.jerico-ri.eu/previous-project/deliverables/d4-3-report-on-biofouling-prevention-methods/
25	JERICO FP7	D5.5, Version 1	Uncertainty estimation for temperature, salinity & chlorophyll-a	2015-02	https://www.jerico-ri.eu/download/filebase/jerico_fp7/deliverables/D5.5_Uncertainty%20estimation%20for%20T,%20S,%20Chl.pdf

38	JERICO-NEXT	D3.5	Conclusion report on FerryBox systems D3.5. Version 1.1.	2015	https://www.JERICO-ri.eu/download/filebase/JERICO_fp7/deliverables/D3.5%20Conclusion%20report%20on%20FerryBox%20systems.pdf
			Other Non JERICO materials		
26	FIX03		Handbook of best practices for open ocean fixed observatories. European Commission, FixO3 Project,	2016-06	The FIXO3 project is no longer available (project finished). The permanent link is here https://repository.oceanbestpractices.org/handle/11329/302
27	CMEMS		QA best practices and protocols on QC for radial and total HF radar data	2017-03	http://www.cmems-increase.eu/static/INCREASE_Report_D3.1.pdf
28	IMOS		Ocean Gliders delayed mode QA/QC best practice manual Version 3.0	2019-04	http://content.aodn.org.au/Documents/IMOS/Facilities/Ocean_glider/Delayed_Mode_QAQC_Best_Practice_Manual_OceanGliders_v3.0.pdf
29			OceanGliders Oxygen SOP v1.0.0	2022-06	https://repository.oceanbestpractices.org/handle/11329/1941
30			Protocols Procedures Data Products QA,QC Calibration Physical Samples	2013-01	
31	EuroGOOS DATA-MEQ Working Group (2010)		Recommendations for in-situ data Near Real Time Quality Control. [Version 1.2].	2010-12	https://repository.oceanbestpractices.org/handle/11329/656
32	EuroGOOS		FerryBox Whitebook	2017-09	http://eurogoos.eu/download/publications/EuroGOOS_Ferrybox_whitepaper_2017.pdf

33	SeaDataNet		SeaDataNet data management protocols for HF Radar data. WP9 - Deliverable D9.12. Version 1.6	2019	https://www.seadatanet.org/content/download/3531/file/SDC_WP9_D9.12_ProtocolsForHFRadarData.pdf
34	Venkatesan R, Ramesh K, Kishor A, Vedachalam N and Atmanand MA		Best Practices for the Ocean Moored Observatories.	2018	doi: 10.3389/fmars.2018.00469 Front. Mar. Sci. 5:469.
35	ICOS ERIC		ICOS Ocean Station Labelling Step 2.	2021	https://doi.org/10.18160/8SDC-K4FR
36	IOCCP & BONUS INTEGRAL		Instrumenting our oceans for better observation: a training course on a suite of biogeochemical sensors	2019	http://dx.doi.org/10.25607/OBP-1041
37	OceanSITES		OceanSITES Data Format Reference Manual NetCDF Conventions and Reference Tables. Version 1.4	2020-07	http://www.oceansites.org/docs/oceansites_data_format_reference_manual.pdf
39	OceanGliders		OceanGliders Salinity SOP	Under review from the scientific community, 2022	https://oceangliderscommunity.github.io/Salinity_SOP/README.html
40	OceanGliders		OceanGliders Salinity SOP	Under review from the scientific community, 2022	https://oceangliderscommunity.github.io/Nitrate_SOP/README.htm

41	OceanGliders		OceanGliders Depth Average Currents (DACs) SOP	In preparation, 2022	https://oceangliderscommunity.github.io/DepthAverageCurrents_SOP/README.htm
42	U.S. Integrated Ocean Observing System		Manual for Real-Time Oceanographic Data Quality Control Flags. Version 1.2.	2020	10.25923/w8y6-d298
43	U.S. Integrated Ocean Observing System		Manual for Quality Control of Temperature and Salinity Data Observations from Gliders. Version 1.0.	2016	https://doi.org/10.25607/OBP-1465
44	SeaGlider		Seaglider Quality Control Manual	2016	https://gliderfs2.coas.oregonstate.edu/sgliderweb/Seaglider_Quality_Control_Manual.html
45	IMOS		Australian National Facility for Ocean Gliders (ANFOG)Data Management Users Manual Version 3.1	2012	https://catalogue-imos.aodn.org.au/geonetwork/srv/api/records/a681fdba-c6d9-44ab-90b9-113b0ed03536/attachments/ANFOG_data_management3_1.pdf
46	ARGO		Argo quality control manual Version 2.9	2013	http://www.argodatamgt.org/content/download/20685/142877/file/argo-quality-control-manual_version2.9.pdf
47	OOI		OOI Data Product Specification for Global Range Test Version 1.01. [OOI, 2012]	2012	https://oceanobservatories.org/wp-content/uploads/2015/09/1341-10004_Data_Product_SPEC_GLBLRNG_OOI.pdf
48	Atlantos		Handbook for Data Management activities regarding data flow and data integration, Atlantos D7.4	2016	https://archimer.ifremer.fr/doc/00370/48139/48242.pdf

49	Atlantos		Report harmonization in data and data processing to facilitate the interoperability of the systems, Atlantos D7.1.	2016	https://www.atlantos-h2020.eu/download/deliverables/7.1%20Data%20Harmonization%20Report.pdf
50	SeaDataNet		SeaDataNet data management protocols for glider data WP9 – Deliverable D9.14	2019	https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5c853ef45&appId=PPGMS
51	OceanGliders		OceanGliders 1.0, Harmonizing format across OceanGliders, Terms of References	2021	https://drive.google.com/file/d/1lcck2Uxm3Yzhu4-k7szj7kkkoSTYVG3W/view
52	Zarokanellos, N.D., et al (2023) In Situ Sensing: Ocean Gliders. In: Blasco, J., Tovar-Sánchez, A. (eds) Marine Analytical Chemistry. Springer.		In Situ Sensing: Ocean Gliders	2023	https://doi.org/10.1007/978-3-031-14486-8_10

○

○ Annex II: Table of sensors used on mature observing platforms

variable/EOV	Platform (MO: 1 Mooring, HF: 2 HF Radar, FB: 3 FerryBox, GL: 4 Glider)	make/model name/no	general description	detailed description	sensor calibration procedure	calibration frequency
Surface and water column currents	MO	Nortek Awac ,Nortek ADCP	ADCP and current meters	https://www.nortekgroup.com/products/ocean-currents	manufacturer calibration	as needed
		Codar SeaSonde	Remote sensing - compact receive-transmit antenna - direction finding technique	https://codar.com/seasonde/	Operator manual available at http://support.codar.com/Technicians_Information_Page_for_SeaSondes/Manuals_and_Documentation_files/Docs/SS_OpManual20130730.pdf	twice / year or when nearby environment changes
Surface currents	HF	Helzel WERA	Remote sensing - antennas array - beam forming or direction finding technique	https://helzel.com/product-detail-wera/	Operator manual available upon request at https://helzel.com/downloads/	twice / year or when nearby environment changes

Dissolved Oxygen	MO, FB, GL	Aanderaa AADI optode 4835/4330/4330F, SBE 63 DO optical sensor	Optode-based measurement of absolute oxygen concentration and % saturation	https://www.aanderaa.com/oxygen-sensors, https://www.seabird.com/sbe-63-optical-dissolved-oxygen-sensor/product?id=60762467729	reference to OBPS or other	e.g. 4-8 weeks (FB), 8-12weeks (GL), as needed (MO) during maintenance cruises
	FB	RBR T.odo (slow version, which has a protective layer over the foil to allow it to be cleared of biofouling)	Optode-based measurement of absolute oxygen concentration and % saturation	https://rbr-global.com/products/sensors/rbrcoda-todo/	Reference to OBPS oxygen optode calibration	~4-8 weeks (FB)
Chlorophyll Fluorescence	FB,MO	Seabird (WETLabs) ECO Fluorometer, ECOFLNTU	Fluorometer	Measures fluorescence from chlorophyll-a, fDOM, uranine, rhodamine, and phycocyanin and phycoerythrin. https://www.seabird.com/eco-fluorometer/product?id=60429374754	Regular manufacturer calibration, as needed.	Every year or every other year, especially if instrument starts drifting
	FB	TriOS microFLU, nanoFLU	Fluorometer	online fluoremeter for precise and selective measurement of chlorophyll a, phycocyanin; https://www.trios.de/en/fluorometers.html	manufacturer calibration, yearly or as needed; frequent checks of instrument drift with solidCAL	manufacturer calibration, yearly or as needed; frequent checks of instrument drift
Colored dissolved organic matter (CDOM)	FB	TriOS microFLU, nanoFLU	Fluorometer	online fluoremeter for precise and selective measurement of CDOM;	manufacturer calibration, yearly or as needed; frequent	manufacturer calibration, yearly or as needed; frequent checks of

				https://www.trios.de/en/fluorometers.html	checks of instrument drift	instrument drift
Temperature	FB,MO	Seabird SBE38 Digital Thermometer, SBE45 Thermosalinograph, SBE 37 CT, SBE 16 CTD	Measures temperature	https://www.seabird.com/	traceable digital thermometer (Platform 1,3,4); factory calibration (Platform 1)	by manufacturer, not specifed, ~ every 1-2 years
Salinity	FB, MO	Seabird SBE45 Thermosalinograph,SBE 37 CT, SBE 16 CTD	Salinity in surface water (flow-through)	https://www.seabird.com/sbe45-microtsg-thermosalinograph/product?id=54627900541	Manufacturer calibration. frequent checks of instrument drift	by manufacturer, ~ every 1-2 years
Turbidity	FB, MO,GL	Seabird (WETLabs) ECO Fluorometer, ECOFLNTU	Scattering Meter	Optical backscattering sensor measuring turbidity: https://www.seabird.com/eco-flntu/product?id=60762467722	Regular manufacturer calibration, as needed. frequent checks of instrument drift	manufacturer calibration, yearly or as needed; frequent checks of instrument drift
	FB	Turner Cyclops	Turbidity (and fluorescence)	https://www.turnerdesigns.com/cyclops-7f-submersible-fluorometer		Regularly (in the lab), as needed
pH	FB	Sensorentechnik Meinsberg	pH	https://www.meinsberger-elektroden.de/en/ueberblick/appl.html#ph	Regular calibration with pH standards (2 or 3) in the field necessary	Every few weeks, depending on accessibility
pH	MO	SensorLab	pH	sensorlab.es/sp200-sm-high-accuracy-situ-ph-sensor	Regular calibration with pH standards and samples for lab analysis	Every few weeks, depending on accessibility

pCO2	FB	4H Jena Engineering HydroC CO2 FT	membrane-based pCO2 sensor, flow-through	https://www.4h-jena.de/maritime-technologien/sensoren/hydrocrco2ftde/	Calibration is done in controlled environment at manufacturer facility + a post deployment calibration is done if possible. Calibration range can vary, with application.	manufacturer (pre- and post-) calibration and post-processing required : https://aslopubs.onlinelibrary.wiley.com/doi/full/10.1002/lom3.10403
pCO2	MO	4H Jena Engineering Contros HydroC CO2; Pro-Oceanus CO2-Pro CV, CO2-Pro ATM	membrane-based pCO2 sensor, pumped head, antifouling protection	https://www.4h-jena.de/maritime-technologien/sensoren/hydrocrco2de/ https://pro-oceanus.com/products/search-results?application=Oceanography&gas=CO2	Calibration is done in controlled environment at manufacturer facility + a post deployment calibration is done if possible. Calibration range can vary, with application	Strongly dependent on the instrument runtime. For Contros HydroC CO2 once a year is usually enough for 1-4 measurement/day. (pre- and post-) calibration and post-processing required https://journals.ametsoc.org/view/journals/atot/31/1/jtech-d-13-00083_1.xml?tab_body=fulltext-display
nutrients	FB	Systea MicroMac C/1000	wet-chemistry methods	http://www.systea.it/index.php?option=com_k2&view=item&layout=item&id=206&Itemid=160&lang=en	Calibration is done in the lab or sometimes in the field, and standards can be used as regular automated checks	Calibration in the lab, according to manufacturer specifications, prior to each deployment
nutrients	GL, FB	Lab-on-chip	wet-chemistry methods	Birchill et al, 2021: https://www.frontiersin.org/articles/10.3389/fmars.2021.698102/full	Regular manufacturer calibration, as needed.	Calibration in the lab, according to manufacturer specifications, prior to each deployment

Plankton and Particles	MO	CPICS camera	imaging system	https://coastaloceanvision.com/cpics/	Regular manufacturer calibration, as needed.	yearly

The JERICO-S3 project is funded by the European Commission's H2020 Framework Programme under grant agreement No. 871153. Project coordinator: Ifremer, France.

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Annex III: DOCUMENT DATA SHEET (for submissions to www.oceanbestpractices.org)

Document Type: **Document Type: *** Select the document format of the item being deposited ○ Book/Monograph: A book or a conference volume or complete serial issue. ○ Book Section: A chapter or section in a book, monograph or conference volume. ○ Journal Contribution: A contribution to a journal ◉ Report: This may be a technical report, project report, documentation, manual or guideline, working paper, discussion paper. ○ Report Section:A chapter or section in a report. ○ Software: Computer programs and applications. ○ Video/Image : A static image or recording of moving visual images made digitally. ○ Web Based Content: Usually a website/webpage. If a document is hosted on a website, use the appropriate document type for the item and include the website URL in the Resource URL metadata field. ○ Other: Something within the scope of the repository, but not covered by the other categories.	Report
Language: Enter the language of the full text deposit, If the language does not appear in the list below, please enter 'Other'. If the content does not really have a language (for example, if it is software, a dataset or an image) please enter 'N/A'. English || Chinese || French || German || Italian || Japanese || Spanish || Other || N/A ||	en
Methodology type: Select the type of methodological document you are submitting. Please select all that apply. Separate entries with a semicolon (;) **Guidelines & Policies** Guidelines & Policies: A set of conventions and options to advice action; an indication or outline of conduct. Policies are generally high-level guidelines on expected or acceptable behaviour, especially of a governmental body **Method** Method: A documented procedure, a step-by-step set of instructions for accomplishing a task. Examples include manuals, scientific/medical protocols, standard test methods and standard practices (e.g. standard operation procedures) **Methodological commentary/perspect** Methodological commentary/perspective: Narrative reflections on or discussion of a methodological document **Description of a metrology standard** description of a metrology standard: Documentation of a physical standard used for metrology (e.g. a manufactured object used to calibrate sensors) **Specification of criteria** Specification of criteria: a description of requirements (e.g. a technical, quality assurance and inclusivity requirements) that a methodology should comply with in order to fulfil the expectations of a community or organisation **Reports with methodological relevance** Reports with methodological relevance: a report of any activity which has relevance to methodology (e.g. a set of existing methods were compared, a report on a field expedition where new technology was tested, or a report on a computational benchmarking experiment) **Training/Educational material**	Specification of criteria; Reports with methodological relevance

Maturity Level If applicable, enter the maturity level of the methodology in the document **N/A**: where maturity level not applicable **Mature**: Methodologies are well demonstrated for a given objective, documented and peer reviewed; methods are commonly used by more than one organization (TRL 7-9) **Pilot or Demonstrated:** Methodologies are being demonstrated and validated; limited consensus exists on widespread use or in any given situation (TRL 4-6) **Concept:** A methodology is being developed at one institution(s) but has not been agreed to by the community; requirements and form for a methodology are understood (TRL 1-3)	Mature
Adoption level: Please indicate how broadly the uploaded methodology is used and/or adopted; please select all that apply. **Novel** (no adoption outside originators) **Validated** (tested by third parties) **Organisational** **Multi-organisational** **National** **International** **N/A**	Multi-organisational; International
Endorsement (author declared): Please enter if your submission (in its entirety) has been endorsed by an organisation or community as one or more of the following: **De jure standard:** A methodology that an official authority has legally declared as a reference or authoritative model. **De facto standard:** A methodology that has become a reference or authoritative model through wide adoption and common use in at least one community of practitioners. **Good practice:** A methodology that has repeatedly produced reliable, fit-for-purpose results with regard to its stated objectives. **Recommended practice:** A methodology that has been recommended for use by an authority, organisation, community, or other group. **Best practice:** A methodology that has repeatedly reproduced superior results relative to other methodologies with the same objective and which has been adopted and employed by multiple organisations.	
Endorsement (external): Please indicate whether this submission (in its entirety) has been endorsed by an organisation or community. Please name the organisation or community that performed the endorsement above	NO
Refereed Status** Has this document been peer reviewed/refereed? Please enter YES, NO or UNKNOWN	NO
Author Last, First Name(s) ** Separate multiple entries with a semicolon (;) e.g.: Smith, Joseph; Jones, H.; (enter the name/s as it appears in the document in the correct order)	Mantovani , C.; Pearlman , J.; Simpson. P.; Corgnati, L.; Ntoumas.M.; Zarokanellos, N..D.; Voynova. Y.G.; Ove Möller, K.;

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Date of Issue (yyyy-mm-dd) ** e.g. 2018-05-21	2023-01-31
Recommended Next Content Review Date (yyyy-mm-dd) Please indicate the date which you believe the document should be revised and updated	2028-01-31
English-language document title ** Entries should be in English. If applicable, include a sub-title after a colon (:) and version number after the title text (e.g. Version 3.2).	JERICO Deliverable 5.2. Electronic Handbook for Mature Platforms: Mooring - HF Radar - FerryBox – Glider.
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Publisher Name(s) ** e.g.: Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER) Please state the Institute's (Issuing Organization) name as it is specified in official communications. Separate multiple publisher entries with a	IFREMER
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Series and/or Document Number(s) If applicable, list creator document identifiers, e.g.: SIP Protocol Series 6; JERICO-NEXT-W2-D2.1.-24112016-V2.0 Separate multiple entries with a semicolon (;).	
External identifiers e.g. DOI:xxxxxx ; ISBN: xxxxxx Separate multiple entries with a semicolon (;).	
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• Other. eg. Publisher: URL	
Contact person - Last, First names e.g. Smith, Joseph	Mantovani, C.
Contact person - Email **	carlo.mantovani@cnr.it
Abstract/Summary ** Free text, Please provide a brief summary of your best practice including, as appropriate, a brief descriptions of what techniques your best practice is about, which ocean environments or regions it targets, the primary sensors covered, what type of data/measurements/observing platform it covers, limits to its applicability and note the community of practice that developed the best practice.	JERICO has been motivating the creation of best practices for over a decade and has documented procedures in all aspects of coastal observations. These procedures come in many forms (e.g., standard operating procedures or manuals) with varying levels of acceptance and maturity. In some cases, there may be multiple procedures to achieve the same objective, with the result that the selection of the best procedure is unclear. This report addresses some of these challenges by introducing a refined scale of best practice maturity levels. These levels cover two key objectives: the status of the methods documentation and the degree to which the methods have been widely and effectively implemented. This is done through "A Best Practices Maturity Model for Methods and their Applications", which is introduced for the first time (see the Introduction for

	more information). The report then collects the best practice documents of JERICO and looks at their levels of maturity. This report addresses best practices in the context of four mature JERICO observation networks: moorings, high frequency radar coastal monitoring, ferry boxes and underwater gliders. These systems are described in detail, covering the platform, the sensors and, with the exception of the moorings, the data management. With this background, the best practices related to each of the systems are given. The practices that exist are important for interoperability and trust in the data, but there are gaps in practices and these will need to be identified and addressed. The three contributions of this report are: 1. an expanded maturity model for best practices; 2. recommendations for further implementation and maturing of best practices for coastal observations; 3. a master table of JERICO and other BPs as a reference

	for mature systems.
Spatial Coverage If applicable, please specify the region where the best practice is applied. For regional term guidance use the following link: https://www.nodc.noaa.gov/worlddatacenter/regions.html. e.g. SW Pacific Ocean	
Sustainable Development Goals, Targets, and Indicators ** If applicable, please specify if the best practice has application for a sustainable development goal. Target number is required and should be entered e.g 14.1 Add Indicator if applicable eg. 14.1.1 Refer to this page for more information: https://sustainabledevelopment.un.org/ Separate multiple entries with a semicolon (;)	14.a
Essential Ocean Variables (EOV)** Copy and paste standard variable names from the list on this link. Separate multiple entries with a semicolon(;) **Enter N/A if not applicable**	
Essential Biodiversity Variables (EBV) Copy and paste names from this link Separate multiple entries with a semicolon(;)	
Essential Climate Variables (ECV) Copy and paste standard variable names from the list on this link (e.g for atmospheric variables not already under EOVs) Separate multiple entries with a semicolon(;)	
Supporting variables Please list here any supporting variables, this refers to variables observed or known from instrumentation or identified in the text and used to calculate the desired EOV, ECV or EBV. Separate multiple entries with a semicolon(;)	
Other Variables Please list here any other variable relevant to your document that are not included as EOVs, ECVs , EBVs or supporting variables above, (e.g. ice accretion, anthropogenic carbon) Separate multiple entries with a semicolon(;)	
Sensors If applicable, please list here the type of sensor/s and manufacturers that are mentioned in the best practice, e.g. Water sampler General Oceanics. Separate multiple entries with a semicolon (;).	
Other Keywords Add any other key words, e.g. Melt pond; Diatoms; Absorption coefficient; Separate multiple entries with a semicolon (;).	Mature platforms; Best practices; Ocean observation;

	Harmonization; Fixed platforms; Moorings; GerryBox; HF Radar; Gliders;
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V1.0.0	**2023-01-31**		**Mantovani, Carlo.**